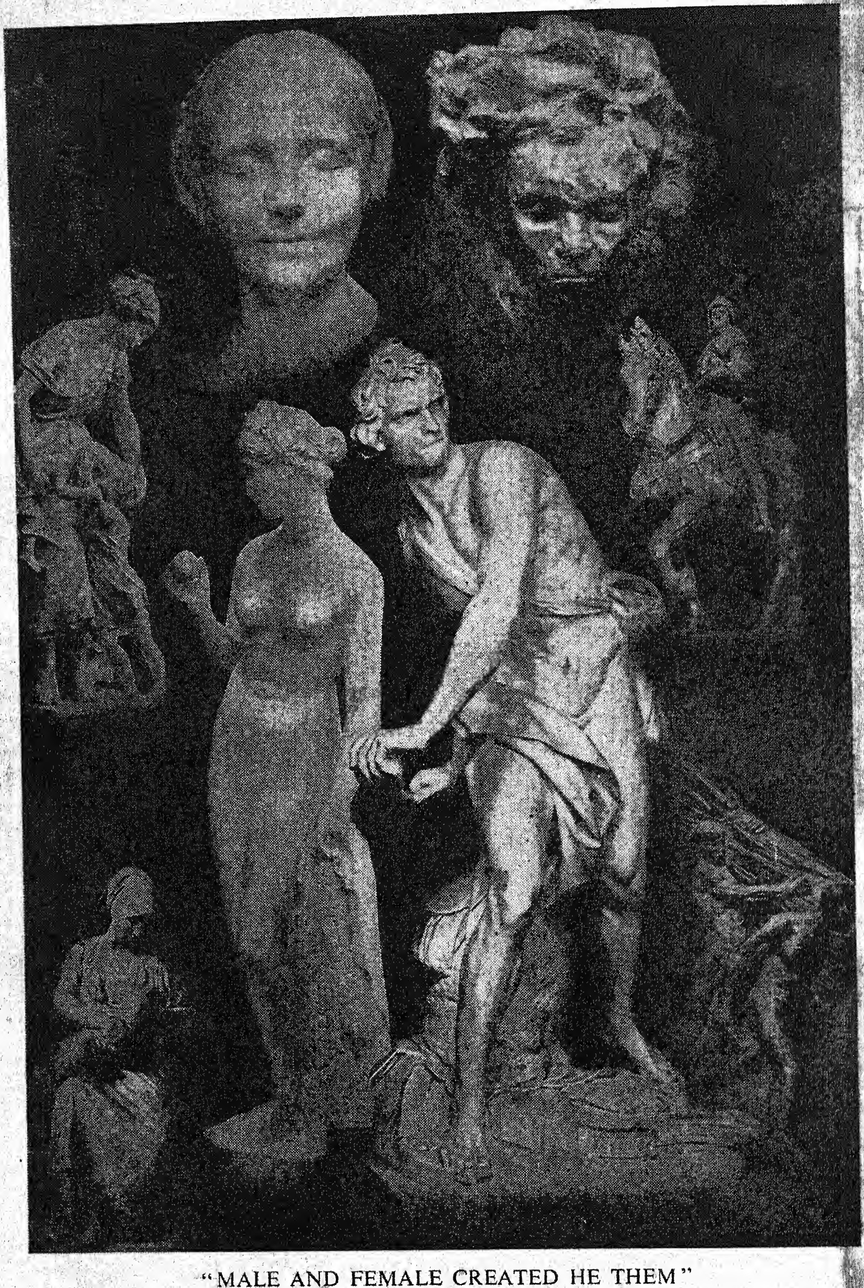


"MALE AND FEMALE CREATED HE THEM"

The dual nature of life—and its essential unity—is clearly demonstrated in the sex characteristics of Man and Woman. Functionally and biologically, as well as mentally and spiritually, each is complementary to, and provides the fulfilment of, the other.

THE SECRET OF LIFE

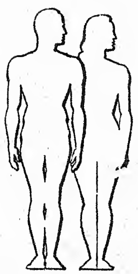
The Human Machine and How It Works

Translated by

GEORGE ROSEN, M.D.

from the original work by

DR. KAHN



ODHAMS PRESS LIMITED · LONG ACRE · LONDON

Wonders are many, and none is more wonderful than man.

SOPHOCLES.

Here is unfolded to us a new and astonishing world.

SIR WILLIAM CROOKES.

Preface

THE human biology of today is not the anatomy of 1880, which began with the statement: "The human body consists of a head, a trunk, and limbs"; nor is it the biology of 1900, which started off with the assertion: "The cell is a small mass of protoplasm with a nucleus in the centre." The human biology of today is the study of man as the centre of the world, of an entirely new, hitherto unimagined world, which the marvellous discoveries of modern science are gradually revealing. The modern biologist's laboratory offers examples in profusion of astounding scientific achievement:

A beating heart is suspended from a small apparatus. It has been beating perhaps for two weeks, receiving salt from this container, hormones through these tubes, and oxygen from this small tank. So it can go on beating for years—the heart of a dead organism!

A research worker looks into the interior of a tube surrounded by a coil condenser; it is an electronic microscope, which can penetrate the unknown six times farther than the most powerful microscope. With it he can follow the path of electrons through the nerve tissue.

Twenty thousand flies in a room, not flying about, but each in its small cage, each identified by a number. Parents, children, grandchildren and great-grandchildren, uncles, aunts, cousins and second cousins—each fly carefully recorded and watched over; for with their help the mechanisms of heredity are being studied, and on the basis of these studies maps of hereditary characters are being made.

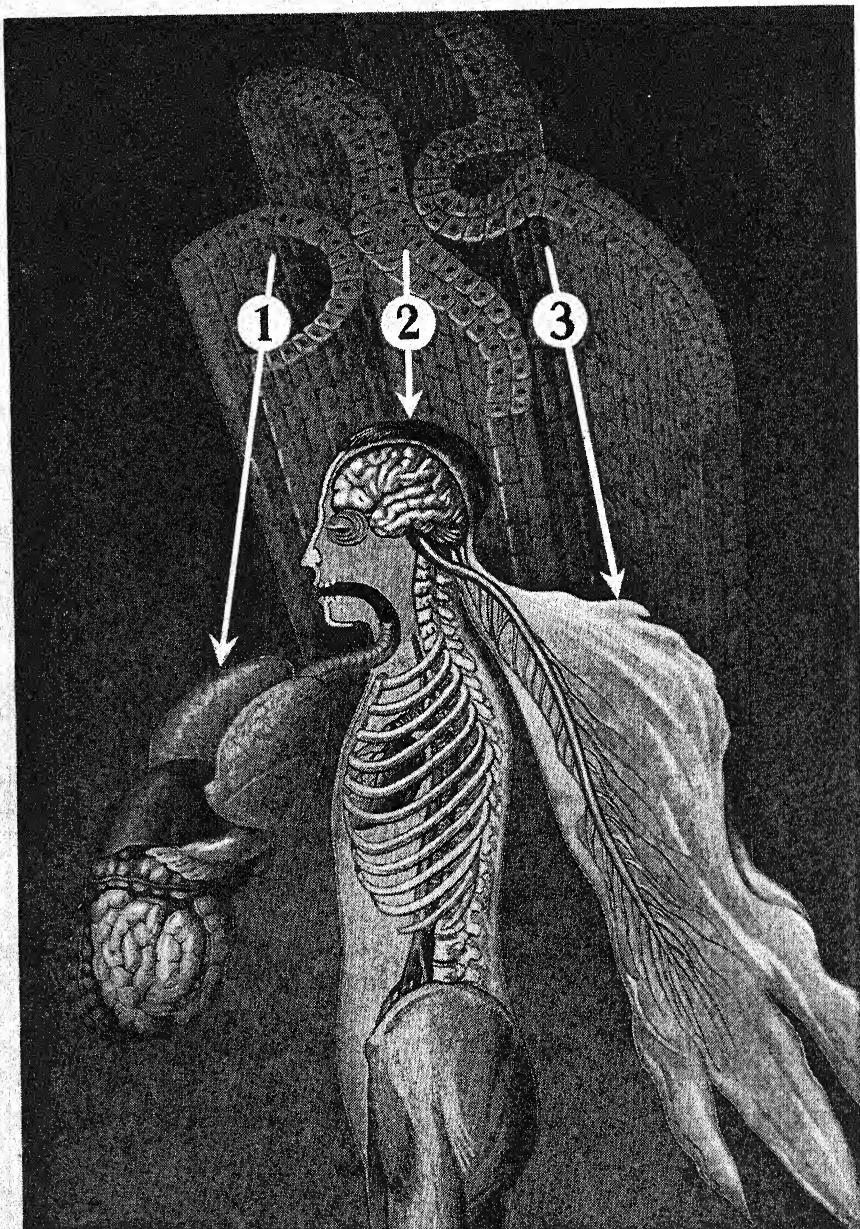
A mother rat feeding a young rat. Nothing very remarkable about that—until we learn from the biologist that the "mother" is a male and not even the youngster's father. A male rat, chosen at random, which, by the magic of modern science, can be turned into a wet nurse, producing milk from his breast, tending the young rat with mother love—mother love from hormone ampoules!

These are the kinds of things that the biologist of today must interest himself in. Not only are they interesting and exciting, but for those with eyes to see and ears to hear they are also full of wisdom of a very practical kind—the modern wisdom of life, which enables those possessed of it to shape their lives according to the precepts of modern science, to increase their abilities, to maintain their health and overcome disease, and to live longer and more actively than their ancestors, although subject to the more compelling urgencies of our age.

Contents

				PAGE
PREFACE				v
I	FROM ELECTRON TO MAN			
	Chapter	I	*Life*	1
	,,	II	*The Development of Man*	17
II	ARCHITECTURE OF THE BODY			
	Chapter	III	*Connective Tissue and Fat*	31
	,,	IV	*Cartilage, Bones, Joints*	43
	,,	V	*The Theory of Body Proportions*	59
	,,	VI	*The Skeleton*	69
	,,	VII	*The Teeth*	95
III	THE MUSCULATURE			
	Chapter	VIII	*Muscle Structure and Function*	103
	,,	IX	*Principal Muscle Systems*	125
IV	THE CIRCULATION OF THE BLOOD			
	Chapter	X	*The Heart*	139
	,,	XI	*The Blood Vessels*	157
	,,	XII	*The Blood*	169
	,,	XIII	*Lymph*	181
	,,	XIV	*Man and Bacillus*	191
V	RESPIRATION			
	Chapter	XV	*The Respiratory Gases*	201
	,,	XVI	*The Nose*	213
	,,	XVII	*The Lungs*	221
	,,	XVIII	*The Vocal Apparatus*	227
VI	DIGESTION			
	Chapter	XIX	*The Problem of Nutrition*	233
	,,	XX	*The Mouth*	243
	,,	XXI	*The Stomach*	253
	,,	XXII	*The Liver and the Pancreas*	263
	,,	XXIII	*The Intestine*	273

			PAGE
VII	METABOLISM		
Chapter XXIV	*Fuel Becomes Energy*	- - -	287
,, XXV	*Nutrition*	- - - - -	293
,, XXVI	*Foods*	- - - - - -	301
,, XXVII	*Mineral Substances*	- - -	309
,, XXVIII	*Diets and Vitamins*	- - -	315
,, XXIX	*Hunger and Thirst; Stimulants*	-	331
,, XXX	*Body Temperature*	- - - -	343
,, XXXI	*Hormones*	- - - - -	355
,, XXXII	*The Urinary Organs*	- - -	369
VIII	THE NERVOUS SYSTEM		
Chapter XXXIII	*The Nerve Cells*	- - - -	379
,, XXXIV	*The Sympathetic Nervous System*	-	391
,, XXXV	*The Central Nervous System*	- -	397
IX	THE SKIN AND THE SENSORY ORGANS		
Chapter XXXVI	*The Skin*	- - - - - -	461
,, XXXVII	*The Sense Organs of the Skin*	- -	483
,, XXXVIII	*Taste*	- - - - - -	491
,, XXXIX	*Smell*	- - - - - -	497
,, XL	*The Ear*	- - - - - -	505
,, XLI	*The Eye*	- - - - - -	527
,, XLII	*The Psychology of Seeing*	- -	569
X	THE PASSING-ON OF LIFE		
Chapter XLIII	*Reproduction*	- - - -	583
,, XLIV	*Sex and Human Life*	- - -	605
	GLOSSARY OF MEDICAL AND TECHNICAL TERMS	- - - -	619
	INDEX	- - - - - - - - - - - -	623



THREEFOLD DEVELOPMENT OF MAN

FIG. 1. *The human body develops from the three germ layers 1, 2, and 3, with the result that it contains three distinct systems of organs. The digestive system develops from the inner germ layer; the skeleton, musculature, vessels, and blood from the middle germ layer; and the skin and nervous system from the outer germ layer.* (*See page 24.*)

I. FROM ELECTRON TO MAN

CHAPTER I

Life

ELECTRON, ATOM, MOLECULE. THE SUBSTANCE OF LIFE: PROTOPLASM. THE MICROSCOPE. THE CELL. CELL DIVISION. CHROMATIN—THE SUBSTANCE OF HEREDITY. BOY OR GIRL? THE SEX CELLS.

THE body is composed of a great many chemical substances, which can be broken down into elementary constituents known as elements. Since the material framework of the body is derived from the environmental medium, within which vital organisms live, these elements are identical with those found in inorganic matter. There are ninety-two elements; of the known elements not all enter into the formation of living matter. Only thirteen enter into the composition of the human body in any important degree, although several others are usually found in small quantities.

Modern Physics

According to the ideas of modern physics the differences between these chemical elements are due to differences in the structure of their atoms. An atom is conceived of as consisting of an exceedingly minute central nucleus around which rotate negative electrical charges termed electrons. These electrons also enter into the structure of the atomic nucleus, where they are combined with positive charges of electricity.

The electron may be regarded as the ultimate structural element of matter. Electrons cannot be seen or held in one's hands, yet we know a great deal about them: their size, the paths along which they travel, and the energies which they develop. Because of this knowledge it is possible to utilize the properties of electrons in various electrical instruments.

Electronic Microscope

One of the most recent of such apparatuses is the electronic microscope, in which, instead of light-rays, streams of electrons are projected against the object being examined. The photographic pictures obtained by using this instrument permit the recognition of structural details which would otherwise remain unseen. The electronic microscope is also extremely valuable for the study of the human body. Despite the fact that this instrument is of recent origin, it has already yielded significant results. With the aid of the electronic microscope a beginning has been made in uncovering the finer structure of bacteria, just as previously the structure of the cell had been elucidated through the use of the ordinary microscope. It

has also made possible the discovery of some of those invisible pathogenic structures, known as viruses, which cannot be recognized by using an ordinary microscope. Furthermore, with the help of the electronic microscope research workers have begun to recognize the finer "ultra-structure" of muscle and nerve fibres and have found that, although the individual molecules cannot yet be seen, they are arranged in rows and in chains. Thus an important advance has been made in uncovering the still hidden mysteries of life. All this is only a modest beginning; these are only the first advances into that newly discovered territory of the electronic microscope, concerning which we know as little as Columbus and his companions did about America when they first saw it.

Revolving Electrons

The electrons in an atom revolve about the central nucleus, so that the atom as a whole may be compared to a solar system in which the electrons revolve around the nucleus as the planets revolve about the sun. Atoms differ in their structure—that is, both in the make-up of the nuclei and in the number and position of the circling electrons. Depending upon its structural arrangement, the atom exhibits certain very constant properties. The number of encircling electrons varies for each element, from one in the hydrogen atom to ninety-two in the atom of uranium. Theoretically there are as many elements as the maximum number of revolving electrons, each element in the series of ninety-two having one more electron circling about the atomic nucleus than the one before it. The simplest element is hydrogen, the atom of which consists of one electron revolving about the nucleus; the largest natural atomic system is that of the uranium atom, in which ninety-two electrons circle about their central nucleus.

The revolving electrons of an atom occupy orbits at several specific levels or distances around the nucleus. A certain definite number of orbits can be accommodated at each level. Thus the innermost level can contain only two electron orbits while the sixth has room for thirty-two.

Giant Molecules

This brief description has been presented so that the reader will have some understanding of how atoms unite to form chemical compounds, since the ability of an atom to enter into combination with other atoms depends on the existence of unoccupied orbits in the most distant orbit level. Atoms that have unoccupied electron orbits are in a state of tension and tend to combine with other atoms, forming groups of atoms called molecules. If two atoms of the same kind unite, a diatomic molecule is formed. Most of the elements consist of diatomic molecules. If unlike atoms combine, the molecular combinations are known as chemical compounds. Two hydrogen atoms (H_2) and one oxygen atom (O) form the chemical compound water (H_2O).

However, the chemical structure of most substances is more complex. Water and salt are the two simplest constituents of the human body. The chemical compounds that are immediately concerned in the vital processes—sugar, fat, protein, vitamins, and hormones—are composed of incomparably more complex atomic structures. In the molecule of the blood pigment 16,669 atoms

are united into one gigantic system.

Such is the ultimate chemical basis of the innumerable chemical reactions in the body that make up the life-processes exhibited by protoplasm, the substance of life.

The Substance of Life: Protoplasm. We do not know what life is. No one has yet observed a transition from inanimate to animate nature, nor has any theory been proposed which successfully explains the origin of life on the earth. We must remain satisfied with the fact of life's existence, without being able to explain it or even describe it clearly. The substance of which living creatures are constructed is called protoplasm [Fig. 2]. On opening a hen's egg we observe a small grey spot floating on the yolk. This is the fundamental substance, the protoplasm of the chick. Look at frogs' eggs, caviar granules, or the roe of a herring. This slimy, grey, insignificant jelly is protoplasm, the most mysterious and marvellous phenomenon of nature: Life. When we at this moment hold this book in our hands, read these words, and think certain thoughts upon seeing these black symbols, it is one of the many incomprehensible properties of protoplasm that enables us to do so.

Protoplasm is not a chemical compound, nor even a mixture of several compounds. It is rather a complex organization of highly differentiated chemical substances. Therefore, even the simplest living being—the amoeba—is called an organism. In order to obtain some idea of the complicated structure of living matter let us compare it with a watch.

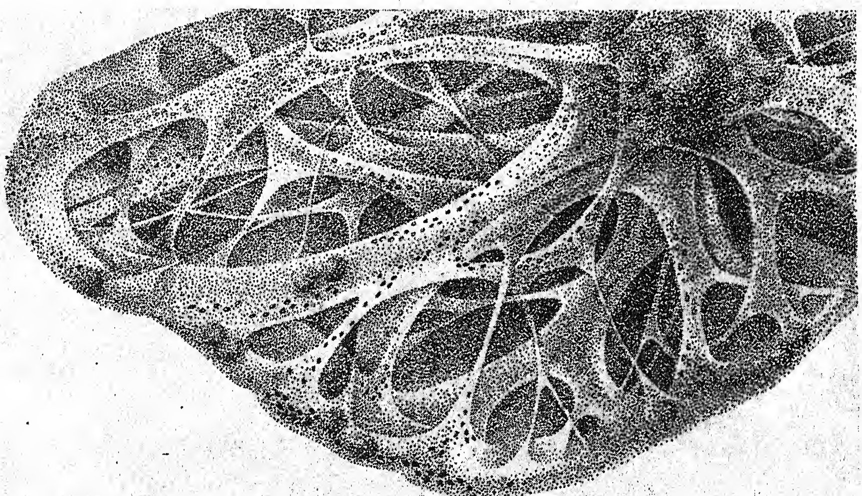


FIG. 2. *The most delicate machine in the world: protoplasm.*

While you are reading this, place your watch before you and consider the complexity of its mechanism. It consists of more than a hundred parts: screws, shafts, cog-wheels of various sizes, springs, hinges, large and small levers, a watch-crystal, a dial, and hands, all systematically and skilfully assembled in a working mechanism of the greatest precision.

Now imagine this watch growing smaller before our eyes. Without losing any part of it or ceasing to function, it becomes as small as a lentil, a rice grain, a sugar granule, and finally it disappears. If we now take a microscope and look for the watch at the spot where it vanished, we rediscover it. Upon magnifying it a thousand times we recognize that the watch with all its parts is still intact and functioning. Imagine, too, that without being wound up, it can go on for years and decades. Such is the picture which we should have in mind when we think of protoplasm: an extremely minute mechanism, constructed according to technological principles, of which, even with the aid of our microscopes, only the very coarsest parts have been up to the present unriddled.

Structure of Protoplasm

Protoplasm consists of fifty per cent or more of water. This is not pure water, but a fluid in which various salts are dissolved. These salts have a large number of functions; for example, they conduct electric currents and are consequently the bearers of electrical energy in protoplasm. The dissolved molecules of these "electrolytes" are constantly in rapid motion and, like the gas molecules in an inflated balloon, exert a pressure outward. This is known as the solution or osmotic pressure, and to it protoplasm owes the tension which it possesses.

Besides the salts various sugars are also dissolved in protoplasm. These substances unite easily with atmospheric oxygen, and are consumed in the process, thus producing the heat required for the vital machinery. A large variety of protein compounds provides the internal structure of protoplasm; and gummous substances, dextrins, and pasty starches render the mass viscid, so that it sticks to a surface.

Incredible Complexity

The iron in the protoplasmatic mass attracts the respiratory gases from the environment and binds them; copper and manganese compounds produce metallic effects; calcium regulates the size of the pores by means of which protoplasm comes into contact with its environment; alcohol and other stimulants energize the organism; vitamins, hormones, and alkaloids of all kinds are also contained in this mixture. In short, the grey mass of protoplasm seen by the human eye is an extremely complex structure.

The Microscope. The most important instrument of biological research is the microscope. When the first microscopists trained their lens-tubes on the objects of their environment, when they began to examine flies, moss fibres, hairs, and chalk suspensions, their astonishment at the "Newly Discovered Profusion of Nature," as a contemporary book is entitled, knew no bounds. Columbus and his companions could not have been more gratified when they first saw the West Indies, nor did they disclose a greater realm to mankind. A truly new world was discovered: the Microcosmos.

Getting Close to Things

Let us imagine that people live on the moon. Hitherto they have seen the earth only from afar as a ball with shadowed surfaces, generally covered by clouds. One day an inhabitant of the moon sets out on a trip towards this ball. And now where he had previously seen

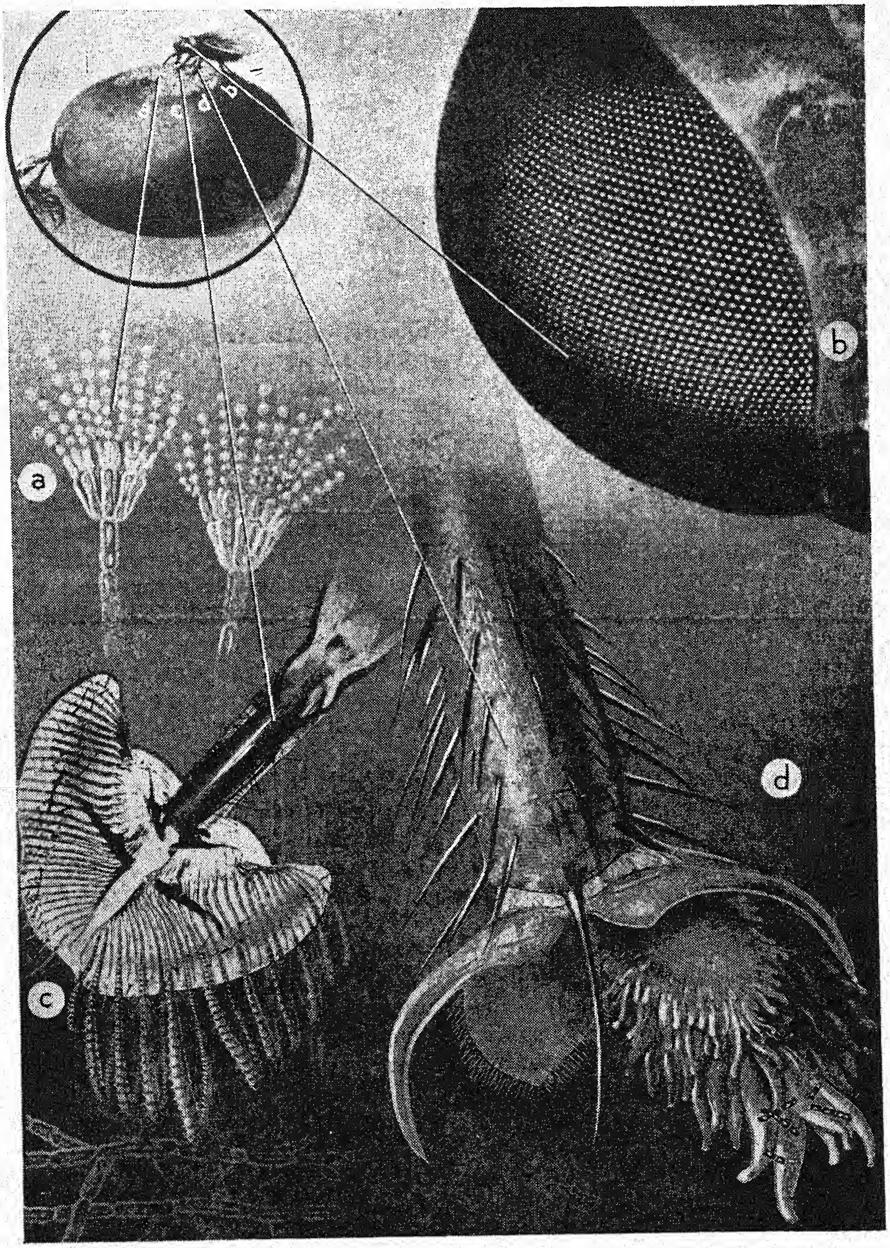


FIG. 3. *The world of the microscope: fruit mould and fly (upper left) under high magnification; (a) the mould threads; (b) the eye of the fly, with thousands of separate lenses; (c) the proboscis of the fly; (d) the fly's foot contaminated with rod-like bacilli. The microscope is one of the most important instruments of biological research.*

only indistinct surfaces, he sees continents and oceans containing islands. As he approaches closer, the oceans take on colour, the islands become green, and he now recognizes mountains, rivers, forests, and fields. At a height of about a mile the traveller from the moon becomes aware of cities, bridges, and railway lines. Upon descending to about two hundred yards he perceives men, animals, automobiles, lights, houses with windows, while behind the windows many smaller things are probably present which he cannot yet recognize at that height.

Through the Microscope

Very similar is the experience of a man who approaches the world beneath him with a microscope. For this is the nature of the microscope: it is an " eye " with which objects can be approached and observed at extremely close range. When thus examined at close quarters, a fly's eye ceases to be a brown spot and reveals itself as a glass-like dome with artfully ground and ingeniously set lenses [Fig. 3 (b)]. Milk is no longer simply a white fluid, but reveals to the microscopist the millions of silvery fat globules and protein particles contained in it. The mould on rotting fruit is not grey " dirt " to be wiped off, but a garden full of the most graceful plants (a). A spider grows so large that it assumes the appearance of a giant crab, while a caterpillar becomes a dragon. On a fly's foot we discover parasites that infest it like fleas, and on these fly-parasites still others can be found—bacilli, which the fly scatters at every step (d). Entire flotillas of algæ sail hither and thither in a speck of surface soil, and an entire world inhabited by fabulous creatures, both plant and animal, can be observed in each drop of water taken from a flower vase.

Even man himself takes on a new and entirely unexpected appearance when examined with a microscope. Anyone who looks at a magnified piece of the human body, no matter from what part, immediately makes one of the great discoveries achieved with the microscope in biology: the discovery that the human body is composed of cells.

The Cell. Just as many substances in inanimate nature, such as salt or diamonds, occur only in the form of crystals, so the vital substance, living protoplasm, appears as a microscopically small unit constructed according to certain principles: *a cell.* The cell is the elementary unit of life, and all terrestrial life is cell-life. No other kind exists. All plants from the smallest alga to a mammoth tree, and all animals from the lowest animalcule to a whale or an elephant, are composed of microscopically small vital units, cells. A blade of grass is a tower, a jellyfish is a glass palace, kelp a long chain, and man a gigantic structure made up of incredible numbers of minute cells.

Structure of the Cell

Despite their minuteness and numberlessness, every cell of the human body is a highly complex organism and is therefore known as the elementary organism of life. Some idea of this structure can easily be obtained, for a giant model of the cell is to be found in every household. Let us take an egg from the pantry, and we have in our hands a model of a cell, magnified approximately a million times [Fig. 4]. If the egg is left in its raw state, we have a model of a plant cell before us (a).

The plant cell consists of a hard external shell containing a semi-fluid protoplasm. The latter is connected with the protoplasm of the neighbouring cells by means of sieve-like holes in the shell, just as the chick in the egg breathes by means of pores in some cases are extremely long. Some cells are highly plastic and, since they lack a firm cell wall, are able to change their shape almost continuously.

Now let us open the cell model. On breaking the egg, the yellow yolk

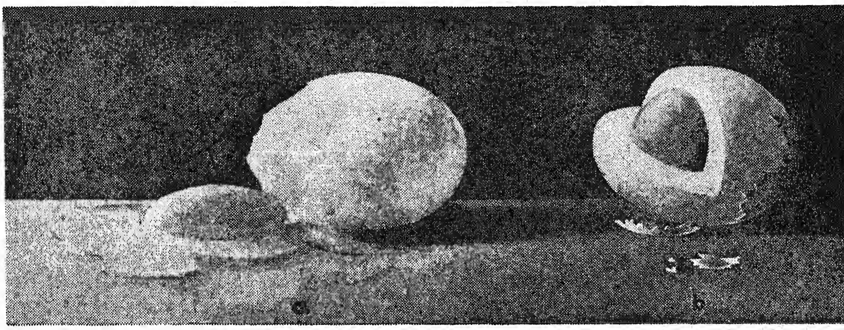


FIG. 4. *An ideal cell model: a hen's egg. (a) a raw egg illustrating the structure of a plant cell; (b) a boiled egg illustrating the structure of an animal cell.*

in the calcareous shell. As the structural element of plant life, the cell must have a hard shell in order to protect the plant against the deleterious effects of wind and sun. If the egg is boiled and the shell removed, we have a model of an animal cell [Fig. 4 (b)].

The forms of cells are almost infinite in variety. An isolated cell tends to be roughly spherical, but very few cells retain this shape, because of the modifying influence of internal forces and external pressures. Massed groups of cells are more or less polyhedral in shape, as any soft masses pressing upon each other would be. Many cells attain highly specialized forms during the embryological stage or in the course of the growth processes of plants or animals. Some rather extreme examples of such specialization are the slender skeletal muscle cells and the irregularly-shaped nerve cells with their numerous fibre processes, which

is seen floating amidst the fluid white of the egg. A cell presents the same picture on a reduced scale [Fig. 5]. It is filled with protoplasm, analogous to the white of the egg, and in the centre floats a sphere, the cell nucleus (d). On closer examination one recognizes clearly that the protoplasm of the cell body (cytoplasm) is not a simple chemical compound nor simply a mixture of various substances, but an alveolar structure like foamy soapsuds. The alveolar spaces are not empty, but are filled with fluids, protein, sugar, and salt solutions of various kinds (a). The alveolar walls consist of firmer substances, such as sticky proteins, gluey starches, and viscid fats. They are not impermeable, but permit certain groups of molecules that are not too large to pass from one chamber to another through invisibly fine "molecular sieves." We must chew, digest, and split up our foods into their molecular parts because they

must later pass through the molecular sieves of the cell walls. The action of medicaments, the rapidity with which narcotic and analgetic remedies take effect, and the rapid action of some poisons also depend on their relations to these molecular sieves. Calcium, for instance, has a sedative effect because it contracts the molecular sieves. The metabolism of the cell, its ability to carry on its activities, and consequently all the activities of the individual are dependent on the state of the alveolar chambers.

The Cell Granules

Within the walls of the alveoli lie granules that present an undifferentiated appearance to our eyes, yet they must actually be formations with a delicate and very varied structure (b). Some contain iron and bind the oxygen of the atmosphere; they are the respiratory organs of the cell. Others attract the food that has entered into the cell and store the nutritive substances. If the cell starves, these storage granules are small; when the cell receives food, they swell and often become visible as oil drops or protein vacuoles (c). In gland cells they produce in the form of granules those extremely complex products which the cell secretes as saliva, gastric juice, or thyroid hormone. By means of their dark pigments certain granules protect cells against the extreme effects of various forms of radiation, and are thus analogous in their function to the resistances or transformers of our electrical apparatuses. Another group of granules controls protoplasmastic movement. They are to be found wherever the cytoplasm executes special movements—for example, at the roots of the cilia in ciliated cells, between the contractile fibres in muscle cells, and near the excretory openings of the glandular cells. Cytoplasmatic granules can be observed with particular distinctness in plant cells. Here they are suspended in fine transparent threads that traverse the cell.

The protoplasmatic granules are very small A million millions fill the space of a cubic centimetre. The human body may contain about $6\frac{2}{3}$ pounds of such granules. One of these granules surpasses all the others exceedingly, in both size and significance, and is called the central body (centrosome) (i). It is so large that " only " one thousand million centrosomes could be packed into a pea. When magnified about two thousand times, one recognizes that it has a well-defined structure. It is the motor centre of the cell and exerts an influence on the protoplasmatic granules, arranging them radially like a sun surrounded by its rays.

The Nucleus

In the centre of the cell lies the nucleus, the most highly organized part, the central organ of the small organism (d). It is a sphere covered by a spirally woven membrane (e). A delicate network can be observed within the nucleus, and in it is suspended a nuclear body (nucleolus) (g). These nucleoli may contain special particles termed nucleolini (h). The most important part of the nucleus is a substance which stains very strongly with certain dyes and is termed chromatin. It was formerly believed that the chromatin was suspended in the nuclear network in the form of granules and spheres, but more modern research strongly suggests that the chromatin substance of the living cell exists only as scattered

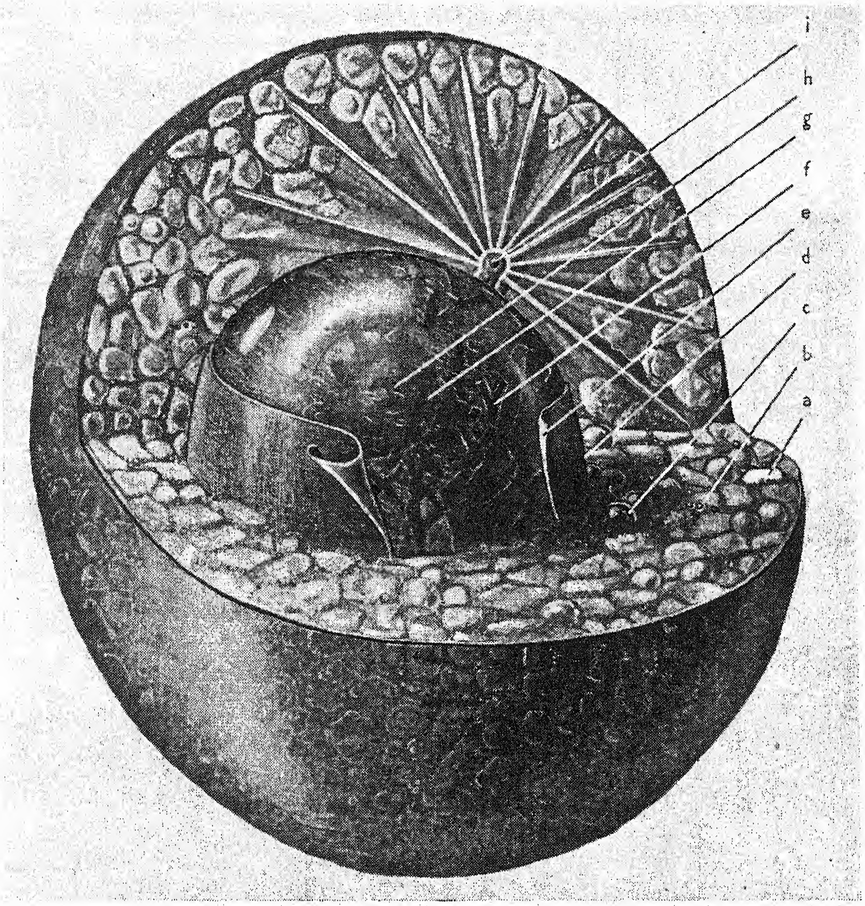


FIG. 5. *The cell, the structural element of the human body. A human being is composed of approximately thirty thousand million cells similar to the one above.*

granules floating freely in the nuclear fluid, or is actually dissolved within the latter. The form and arrangement of the chromatin within the nucleus may be observed to undergo various changes during different phases in the life of the cell. These changes become most evident during the division or reproduction of the cell (mitosis).

Cell Division. The division of a cell is an exciting, one might almost say dramatic, process which belongs to the most remarkable phenomena of nature. It takes place in the following phases [Figs. 6 and 7]:

1st Phase (1): The nuclear membrane becomes indistinct. The centrosome, situated near the nucleus, becomes larger and more prominent, and the protoplasmatic granules in its vicinity arrange themselves concentrically about it like the rays around the bright head of a comet.

2nd Phase (2): The centrosome divides into two parts, and the two

halves move apart, accompanied by their rays. The nuclear membrane vanishes, and the chromatin particles become transformed into a single, spirally convoluted strand, called the spireme. This chromatin spiral assumes a central position in the cell.

3rd Phase (3). The central bodies with their rays travel to the opposite ends of the cell and finally face each other like the poles of the earth. In the course of this journey each centrosome has taken with it one half of the cytoplasmatic granules. The chromatin spiral in the centre of the cell then breaks up into a definite number of rods, called chromosomes, whose number is characteristic and constant for all the cells of each animal and plant species. The number of chromosomes varies from a single pair in some forms to at least sixty-four in others. In one variety of the worm *Ascaris megalocephala* there are only four chromosomes; in grasshoppers twelve; the onion, wheat, and the guinea pig have sixteen; the frog and the mouse, twenty-four; and man, forty-eight.

4th Phase (4): The chromosomes arrange themselves radially around the equator of the nucleus between the poles of the cell, forming a star-shaped figure—that is, when viewed from either pole of the cell, the V-shaped chromosomes look like a star. Arrange six hairpins in a circle about a point in such a manner that the curved ends of the pins are all directed towards the central point. This is the situation of the chromosomes in the centre of the cell during the fourth phase of cell division. Or cut an apple or a lemon into two equal parts between the two poles of the fruit, and the central core with its seeds will represent a model of the dividing cell. Each chromosome now splits lengthwise into two exactly equal halves, thus doubling their number.

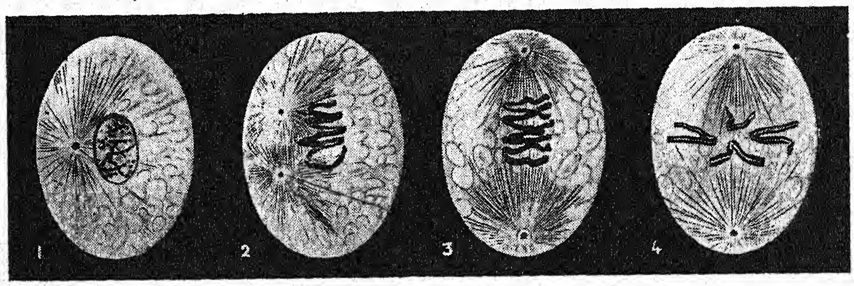


FIG. 6. *The first four stages of cell division, showing formation of the chromosomes.*

5th Phase (5): The halves separate and, as if attracted by a magnetic force emanating from the central bodies, bend towards their respective centrosomes with their curved ends. At the same time the two groups of chromosomes begin to move away from each other.

6th Phase (6): The chromosomes pass to the opposite poles and separate completely.

7th Phase (7): After reaching the poles the chromosome rods merge into chromatin networks similar to that seen in the original mother cell. The protoplasm of the cell begins to divide in the equatorial plane soon after the separation of the chromosomes. The spirally woven nuclear membrane begins to re-form once more around the chromatin.

8th Phase (8): Finally the nuclear membrane becomes complete, and the cell body divides into two separate parts. Now two resting cells take the place of the single one with which the entire process began. The division of the cell is ended.

Chromatin — the Substance of Heredity. Cell division (mitosis) is a complex process. The process is so complicated because the cell itself is not so simple as it may appear to our coarse senses, but is actually a very delicate and intricate organism, which, like the human body as a whole, does not permit of a rough division into two parts, but can be divided into two daughter cells, capable of carrying on all vital activities, only by means of a methodical and systematic division of each of its "organs." The central point of the process is the exact, one might almost say pedantic, division of the nuclear chromatin. This substance is collected at the beginning of division, the granules form a convoluted filament which is unrolled and cut up into a definite number of pieces, and the pieces are arranged in a circle as if they were being mustered for inspection. After being straightened out and found to be equal in size, each single piece is now divided longitudinally into two equal halves.

This extremely precise division of the chromatin presents the appearance of a juridical act, and it actually is one—it is a division of an inheritance. The entire process of cell division could be entitled: the just inheritance. Each daughter cell receives exactly one half of the chromatin stock of the mother cell, since chromatin is the most important substance of the cell. Indeed, it is the most important substance in the world, for it is the material basis of the hereditary characteristics of the cell, and consequently of the entire organism. Chromatin is the hereditary substance of life.

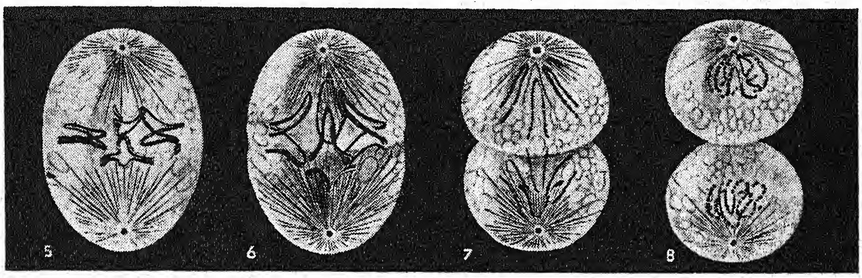


FIG. 7. *The last four stages of cell division: the original cell becomes two cells*

The fruit-fly Drosophila has become one of the most popular creatures in scientific research. Overnight, so to speak, it has become world famous and has attained an immortal position in the history of biology. To be sure, the harmless little insect is quite unaware of all this. In the cells of this fly, however, the chromosomes are very large, particularly during mitosis. By studying these giant chromosomes it was possible to recognize that they are composed of a number of sections and to determine the nature of these parts. The chromosomes are composed of a number of transverse sections. Each section is a genetic element; that is, it contains certain hereditary characters grouped to-

gether and "coupled" in a fixed arrangement. Do not ask how this is done, because we do not know as yet. Nor can we form any idea of the actual structure underlying the fact that microscopically small sections bear hereditary characters within themselves. The hereditary groups contained in these sections are called

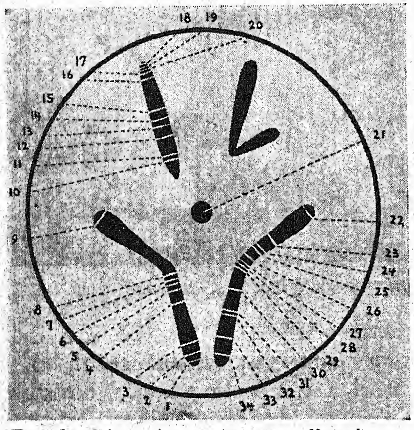


FIG. 8. *The "chromosome map" indicates the positions of the genes in the chromosome, and thus the hereditary characters contained in it. In the above map each number corresponds to a hereditary character of the eye with regard to its colour as well as its form.*

"genes." In the fruit-fly each gene is only 0.00002 mm. wide; while 15,000 to 20,000 genes are contained in one section of a chromosome.

The genes are geographically distributed within the chromosome. Just as one can immediately tell when looking at a map of the world, even though names are missing, that this is India and that is Australia, here is New York and there Cape Town, similarly an expert looking at a chromosome in the cell of the fruit-fly Drosophila can tell us that the factor for wing form is situated here, and there is the location of the factor for the lower joint of the anterior extremity. It is possible to do this because the arrangement of the genes within the chromosome is as exact as that of the catchwords in a dictionary.

In man the circumstances are essentially the same, but owing to various causes it is much more difficult to investigate human cells. Human egg cells contain 48 very small chromosomes that are difficult to differentiate, and these certainly contain 10,000 times as many genes as the corresponding cells of the simple fruit-fly, whose activities are restricted to relatively few movements, sensations and reactions.

Chromosome Maps

It will no doubt be a long time before it will be possible to produce human chromosome charts like those of the fruit-fly and other insects. But science advances constantly. It recognizes no obstacle and knows not the meaning of "never." The science of the future will undoubtedly be able to give us human chromosome maps.

Boy or Girl? The transmission of hereditary characteristics from parents to children takes place during fertilization. During this act a paternal cell, the sperm, unites with a maternal cell, the ovum or egg. The union of these two cells gives rise to the ovum-sperm cell, from which the child develops.

The number of chromosomes is constant. A simple union of the two sex cells would result in a doubling of the number of chromosomes. To prevent this, however, every germ cell passes through a modified mitosis to fit it for taking part in the reproductive process. This modified form of cell division is called maturation

or ripening of the sex cell. In this process the chromosomes do not split lengthwise as in ordinary mitosis; instead half the chromosomes pass to one daughter cell and half to the other. Thus the original number of chromosomes is reduced by half.

Sex Chromosomes

Moreover, since the chromosomes carry the factors which determine the hereditary characters, and no two chromosomes are identical in composition, it is evident that this process is extremely significant for the heredity of the future individual. The unripe human sex cell contains 48 chromosomes, the mature cell only 24.

The chromosomes are arranged in pairs. The two carrying the hereditary determiners of the child's sex are called sex chromosomes. In female cells they are externally alike and are called X-chromosomes [Fig. 9]. In male cells they are dissimilar. One is an X-chromosome; the other, however, differs from its partner, being characterized by the presence of a hooked end, and is called the Y-chromosome (upper row). We can tell from the cells whether they derive from a male or a female. The Y-chromosome is found only in males. During the maturation division, females form sex cells bearing only X-chromosomes. Of the male sex cells one half contain X-chromosomes, the other half Y-chromosomes (middle row). The mathematics of fertilization and sex determination is simple. If a female cell unites with a male cell containing an X-chromosome, a child cell with two X-chromosomes is produced: a girl. However, if the female cell unites with a cell carrying a Y-chromosome, a cell containing X + Y-chromosomes arises: a boy. This simple calculation is the basic mystery of sex determination. It depends solely on the father. All previous and in part highly fantastic theories are thus superseded. In the future it may even be possible to determine the sex of unborn children. Not by astrology or special elixirs, however, but only by exact scientific methods. For the sake of simplicity the chromosomes of the fruit-fly have been re-

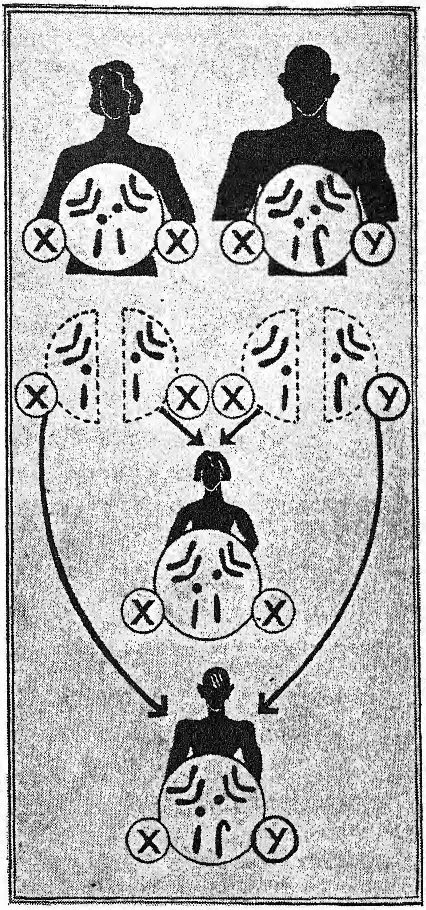


FIG. 9. *Boy or girl? Human sex cells with XX-chromosomes become girls; only cells with XY-chromosomes can become boys.*

presented in Fig. 9 instead of human chromosomes. Actually the human cell contains 48 chromosomes that are very difficult to differentiate from each other. The female chromosome formula is 46 + 2X, that of the male 46 + XY.

Certain hereditary characters are borne by the X-chromosome of the female, and are consequently carried by the female to a portion of the male descendants. In such cases we speak of the hereditary factors as being sex-linked.

Two examples of such sex-linkage in man are colour-blindness and hæmophilia. These conditions appear only in male descendants, while females do not themselves suffer from these conditions, but serve only as carriers. Perhaps it will be possible some day to explain various specifically male and female characteristics on the basis of the position of particular genes in the sex chromosome.

The Sex Cells. The male and female sex cells, whose union provides the starting point for the development of the child, vary greatly in their external appearance, owing to the very different parts that they play in the reproductive process. The female sex cell is relatively heavy and stationary, so that the sperm must travel towards it in the necessary process of getting together. The former is a large sphere, the largest cell in the body. It has a diameter of 0.2 mm. so that with good illumination it can just be recognized by the naked eye as a tiny dot.

With a weight of 1/200,000 gm., the egg cell may appear minute to us, but for the microscopic world it is a true "heavyweight." It is stored with granules of sugar, starch, and protein for the nutrition of the future

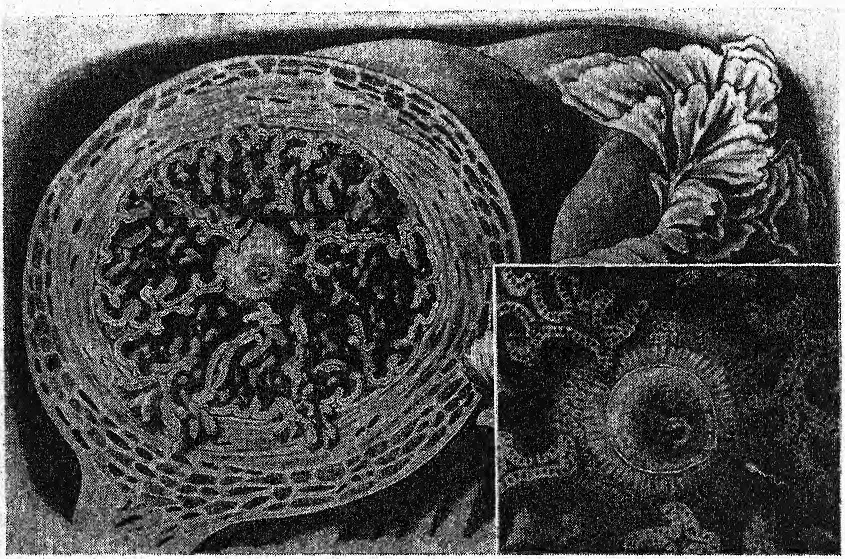


FIG. 10. *Fertilization of the egg cell by the first sperm cell to arrive. A view inside the oviduct, where one of several sperm cells can be seen penetrating the much larger egg cell. At lower right is an enlarged view of this process.*

organism during the early stages of its development [Fig. 10].

The male sex cell must travel to the female for fertilization to take place, and is therefore adapted for rapid locomotion in a fluid medium. Each sperm cell in man is about 1/500 of an inch long, and 100,000 sperms could find place in an egg cell. When examined under the microscope, a number of interesting structural details can be discovered about the sperm cell.

The Male Cell

Each sperm cell consists of three parts: a head, a middle section or body, and a long tapering tail. In human sperms the head has an oval shape, somewhat flattened towards the apex, so that it appears pointed when viewed in profile. The apex of the oval is covered by a cap which is really a delicate film of cytoplasm and is called the head-cap or acrosome. The great mass of the head consists of chromatin, the hereditary material derived from the father and containing the multitude of genes that go to make up the human character. Immediately behind the head lies the motor of the sperm cell, the centrosome.

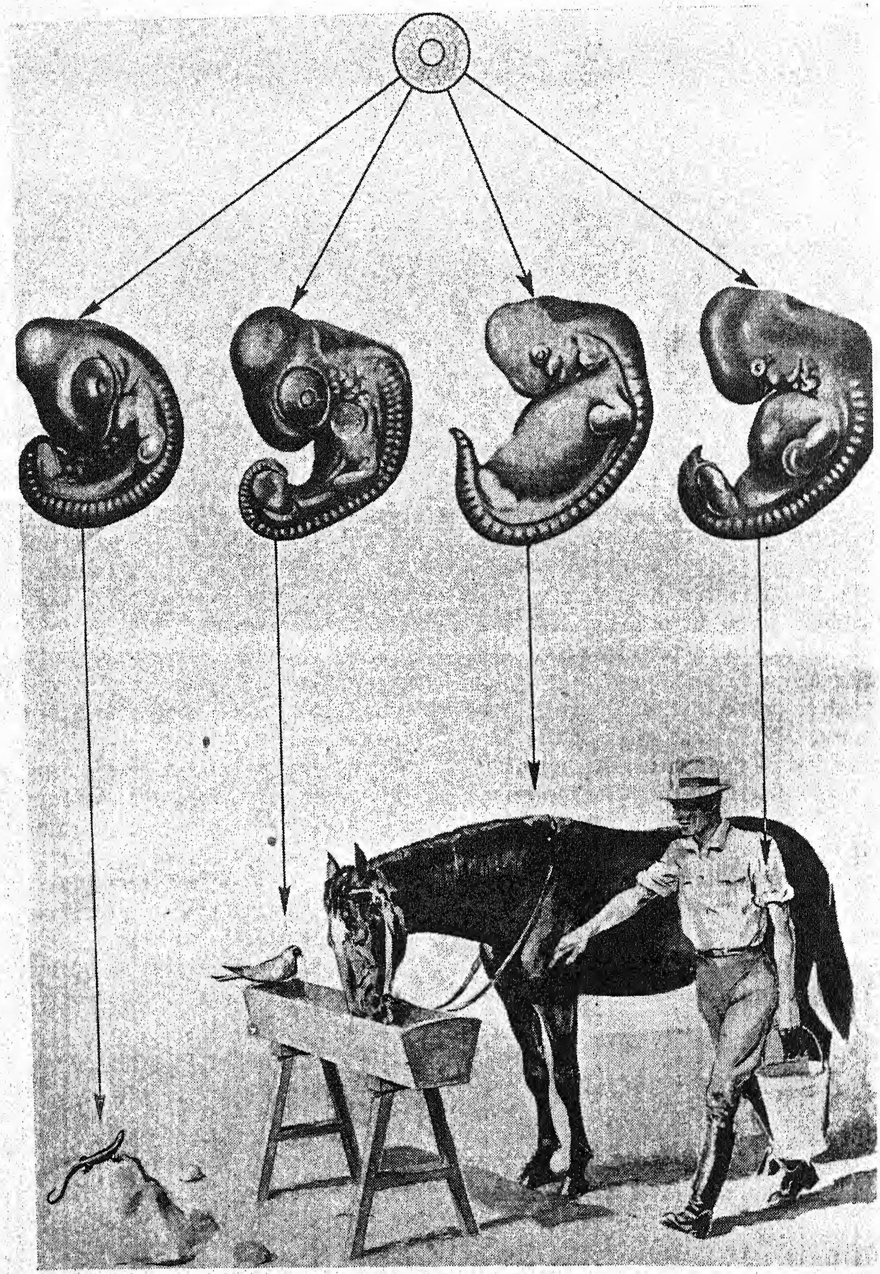
The body or middle of the sperm is short and cylindrical in man, and has a spiral fibre passing around it. From the centrosome another long fibre, called the axial filament, passes right through the body and tail of the sperm. The longest part of the cell is the tail, which acts as a propeller and drives the sperm forward. When examined under the microscope in a fresh state, the tail is seen to execute rhythmic spiral and lateral motions.

A Perfect Motor

In order to reach the egg cell, this human sperm torpedo must traverse a distance of 10 in. This is quite a distance for a cell which, despite its long tail-piece, is hardly 1/500 in. long.

The sperm cell is able to travel 0.11 in. per minute. In ordinary circumstances it would take from four to five hours to reach its goal. Usually, however, owing to disturbing conditions in the genital passages, it takes much longer to travel the same distance.

During this uncertain journey the cell motor may have to run uninterruptedly for days—indeed, even more than a week. The sperm carries no reserve fuel tanks with it and finds no filling stations for refuelling on the way. It must reach its goal in a non-stop flight, and it is indeed one of the best " fliers " in the world.



REPTILE, BIRD, ANIMAL—OR MAN?

FIG. 11. *Not only as an egg but even in the third week of embryonic development man cannot be differentiated from a reptile, a bird or other animal. The illustration shows the embryos of these creatures at stages corresponding with the third week in man.*

CHAPTER II

The Development of Man

FERTILIZATION. THE DEVELOPMENT OF BODY FORM. THE FORMATION OF THE ORGANS. THE BIOGENETIC PRINCIPLE. DEGENERATE ORGANS.

OUR life begins with a sporting event—a race. For the generation of a human being 225 million sperms line up for a "race for life," dash off, and compete with each other in an eight-hour marathon, whose goal is the maternal ovum. This marathon is a true race for life. Whichever of the 225 million male competitors reaches the egg cell first and fertilizes it wins the prize, the grand prize—life. All the others must die, for when the first sperm cell has penetrated into the egg, the surface membrane of the ovum congeals behind it, and all the "late comers" must remain outside the closed gate, where they swim about, twisting and turning, until they grow weary, and die of exhaustion [Fig. 10].

Survival of the Fittest

The race of the sperm cells to the egg is a genuine elimination race. Whichever sperm most quickly traverses the distance and finds the hidden egg first and, upon the arrival of the leading competitors at the egg, still possesses the power to penetrate the membrane of the egg most rapidly, receives the prize of the triply-tried victor and becomes the child of its parents. Just as in most of our sporting events, this race also has its injustices, accidents, mishaps and undeserved favours. It is by no means always the most valuable sperm that propagates itself, and we have no right to believe that we who have won are "the elect." However, when considered in terms of the many billions of cases that occur in actual life, the final result is generally a fair one, just as in human sport. By means of the great elimination race of the sperms with which human life begins, nature effects a selection of the fittest, propagating the strong and eliminating the weak.

Moment of Destiny

After entering the egg the sperm throws off its long propeller-tail, assuming once more the appearance of a nucleus, while the middle piece or body is again transformed into a centrosome characterized by its prominent corona of rays. Like an ice-breaker preceding a steamer, the latter body opens a path among the protoplasmatic granules so that the chromatin-laden head can approach the nucleus of the egg cell.

The two nuclei now face each other surrounded like two suns by the rays of their respective central bodies. The chromatin within them appears in the form of granules, the granules unite to form strands, and the nuclear membranes disappear. The chromatin strands of the two cells now lie freely alongside of each other and begin to mingle. This is a moment of destiny in the life of man, one of the most important moments of his entire life, for at this moment

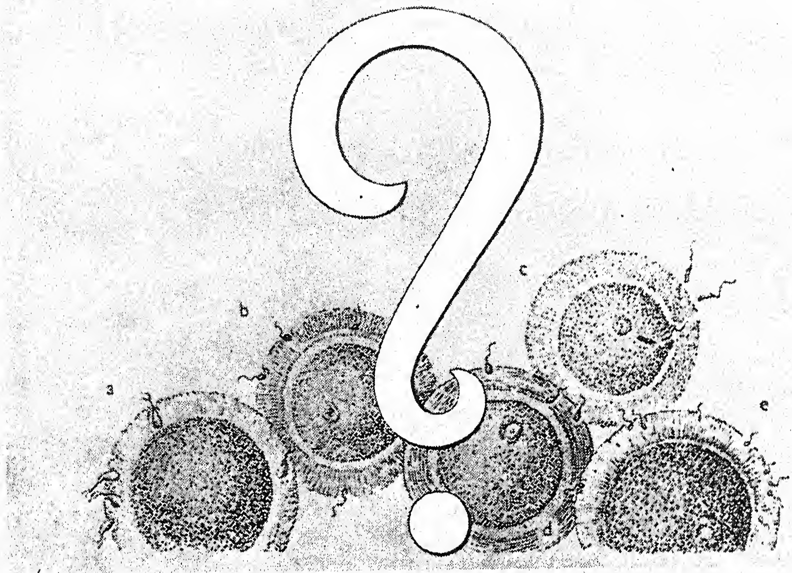


Fig. 12. *A puzzle: what five forms of life would you expect to develop from these five separate and independent acts of fertilization?*

his structure is being determined. The entire process resembles the shuffling and dealing of a pack of cards at the beginning of a card game. Trumps are dealt here, aces there, worthless cards elsewhere, and the game which now begins, and which willy-nilly we must begin with the cards dealt us, is the game of life. At this moment two entirely different people, a man and woman, mingle the variegated halves of their characters. They come from different families that in the course of millennia have accumulated very diverse hereditary characters, as a result of repeated mixtures with still other families. Thus they may contain many harmonious characteristics, and just as many dissonant ones. It is evident that the origin of a human being, as a result of the union of two individuals, is an involved matter.

The Development of Body Form. Shortly after the union of the two nuclei, the egg-sperm cell begins to divide [Fig. 14]. The initial cell is divided in turn into two, four, eight, sixteen, thirty-two cells, until a mass of small cells resembling a mulberry (morula) results. Fluid collects within this mass so that the ball of cells becomes a hollow sphere, called a blastula. The sphere grows longitudinally and becomes flattened, with the result that the walls approach each other and ultimately come to lie close together [Fig. 15]. This flat, sole-shaped structure, with its two layers, is called the germinal disk, and is composed of the primary germ layers. The upper outer one is the external germ layer (ectoderm); the lower internal one is the inner germ layer (entoderm).

In the mid-line, extending from

one end of the blastula to the other, the two layers are united to an axial cord. From this cord a third middle germ layer (mesoderm) grows between the two primary ones.

The human form develops from these three germ layers according to very simple principles. What does a child do when it wants to make toys—little boats, for instance—from flat sheets of paper without any technical aids? It folds, bends, and creases the sheets, fastening the edges together. Nature does exactly the same when it forms the human body from the three flat germ layers.

First of all, the lower inner germ layer bends downwards until the free edges meet and grow together. The flat germ layer has become a tube, the primitive gut, which passes through the human body along its long axis [Fig. 16].

Then the upper germ layer begins to bend, but not only in one direction like the lower layer [Fig. 17]. At first it bends like the lower germ layer with its free edges downwards

FIG. 13. *The solution: although the egg cells were indistinguishable (a) becomes a seaweed; (b) a human being; (c) a sea-gull; (d) a horse; and (e) a starfish. The nature of the elements which determine the line of development is quite unknown.*

until they meet, giving rise to a larger tube enclosing the entire embryo. Secondly the portion of the germ layer directly above the axial strand becomes depressed along its centre, while the more laterally situated sections begin to arch upwards, producing a groove (neural groove). The arched edges continue to grow upwards and towards each other until they meet and fuse, forming a tube (neural tube). Our nervous system is a tube, which traverses the body like the intestinal tube and parallel to it. The neural tube does not remain on the surface, but is depressed in the process of formation so that it comes to lie under the integument. Man's body is essentially a three-tube system. Within a large tube (integumentary tube) hang two narrower tubes: the intestinal and neural tubes.

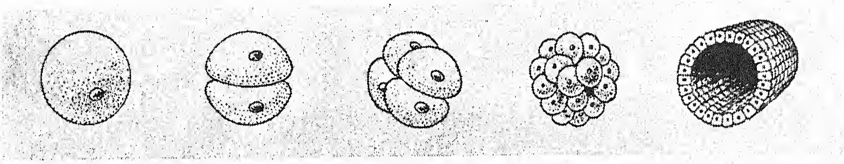


FIG. 14. *The first hours of human life: the egg cell develops into the blastula, which is a hollow, circular vessel with walls one cell thick.*

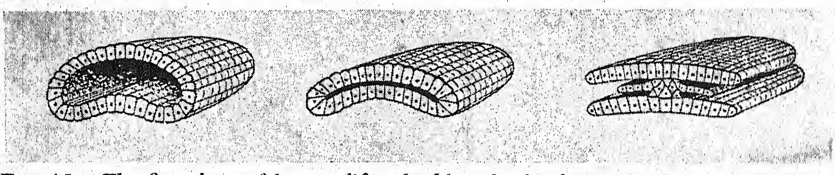


FIG. 15. *The first days of human life: the blastula develops into the gastrula by the flattening of the vessel till its opposing walls meet.*

The middle germ layer fills the space between the other two [Fig. 18]. In the central axis it thickens to bone and forms the skeleton (1). Laterally the tissues remain soft and develop into musculature (2). Some of this embryonic tissue remains spongy, with many intercellular spaces that coalesce to form hollow tubes, the blood- and lymph-vessels (3). At the same time the blood which fills this vascular system also develops from the mesoderm. Thus bones, muscles, the vascular system, and the blood arise from the middle germ layer.

The Formation of the Organs. The organs of the body are also developed according to simple principles from the three primary tubes and the central axial cord.

I. The organs of the entoderm [Fig. 19]. The intestinal tube becomes dilated in the middle, giving rise to the stomach, which divides the intestinal canal into two sections, the anterior (œsophagus) and the posterior portions (intestine). The posterior part becomes greatly elongated, leading to the formation of many loops and coils as a result of the enormous increase in the length of the tube.

Not only, however, does the intestinal canal coil up as a whole, but in each region the internal surface of the tube begins to develop folds, projecting into the lumen (cavity) of

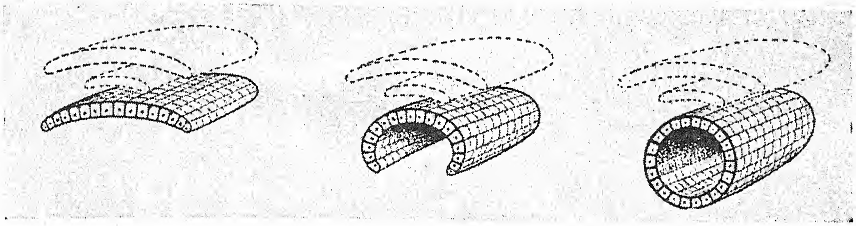


FIG. 16. *The lower germ layer rolls up to form the gut.*

the canal, as well as depressions in its wall [Fig. 20]. This folding process results in the production of the large circular intestinal folds, and the delicate little hair-like processes (villi) which are situated so close to one another that they give the surface of the intestinal canal a velvety appearance [Fig. 20, lower row]. On the other hand, the depressions in the wall of the tube represent the most primitive stage in the development of the intestinal glands. Glands are essentially involutions of the wall of the alimentary or integumentary tubes, which produce glandular secretions as a result of cellular activity. At first the gland pits are shallow and simple. Then they grow deeper, develop secondary branches, and as a result of this extensive process of arborization finally give rise to such organs as the liver and pancreas that we see attached to the intestine [Fig. 20, upper row].

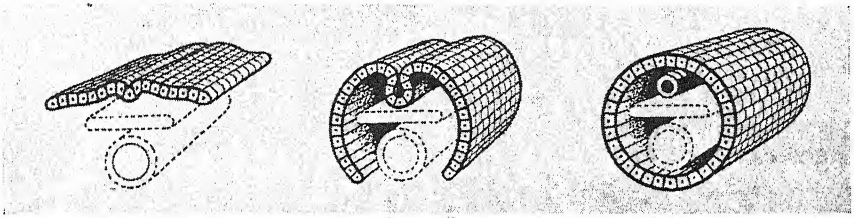


FIG. 17. *The upper germ layer forms the integumentary tube and the nerve tube.*

II. The organs of the external germ layer. The open ends of the neural tube close [Fig. 21]. The anterior end expands, forming the primitive brain vesicle. Owing to the restricted space within which it develops, it becomes flexed and coiled,

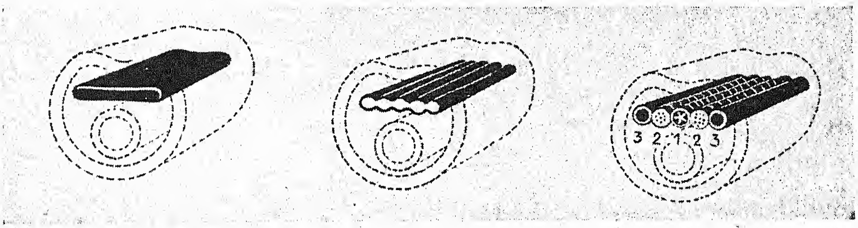


FIG. 18. *The middle germ layer forms the vertebral column (1); on either side of this arise the muscles (2) and the blood-vessels and lymph-vessels (3).*

analogously to the growth of the intestinal tract, ultimately leading to the production of the various parts of the brain. At first the surface of the brain vesicle is smooth, but as the process of development proceeds, the unequal growth of the various portions of the brain gives rise to a folding of the surface, with the resultant production of the convolutions and fissures which give the brains of the higher animals their characteristic appearance. This process of folding is due partly to development in a confined space, and partly to the relation between the grey and white matter of the brain. The grey matter exists as a relatively thin layer in comparison with the white matter, which increases in thickness as the brain grows. In consequence the grey outer layer begins to buckle and fold, producing the convolutions of the brain surface.

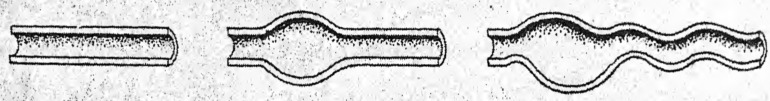


FIG. 19. *The gut (left) expands in the middle to form the stomach (centre), while the posterior portion develops into the winding intestinal loops (right).*

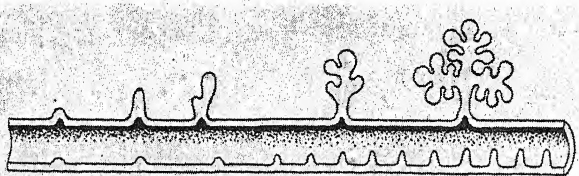


FIG. 20. *The wall of the gut invaginates to form folds and villi (lower row) and evaginates to form glands (upper row).*

Like the wall of the intestinal canal the skin also develops various invaginations [Fig. 22]. Some develop as hairs, others as sweat glands and some develop into sebaceous glands.

III. The organs of the middle germ layer. The development of the middle germ layer takes a very different course. It becomes divided into segments [Fig. 23]. In the solid axial cord (a) appears a series of some thirty clefts situated one behind another, so that the originally smooth rod is transformed into a segmented structure resembling a string of beads. The clefts deepen and the segments become separated. The axial cord now consists of 33 segments called vertebræ (b), and has become the vertebral column or backbone. The function of the vertebral column, and of the skeleton as a whole, is to protect the "soft parts" of the body and to furnish points of fixation for the motor organs of the body, the muscles. For this reason the developing backbone or skeletal axis grows around and encloses the two tubes between which it passes. It grows upwards around the neural tube so that the latter structure comes to lie within the spinal column, and down-

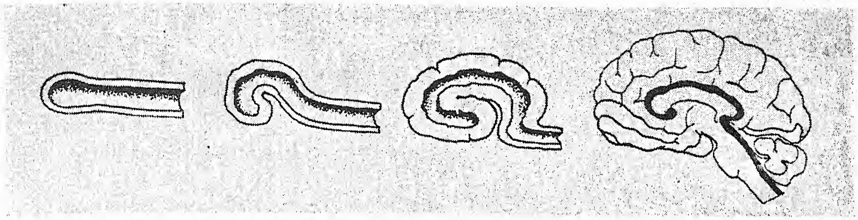


FIG. 21. *The neural tube folds up and its anterior end thickens and becomes the brain.*

wards to encircle the intestinal tube with broad bands of bone. These bones that encircle and protect the viscera are the ribs (c). In land vertebrates limbs for locomotion—arms and legs—grow out of this central skeleton.

Harmonious Development

Thus it is quite evident that the development of the skeletal axis proceeds in an intimate and fundamental relationship with that of the nervous system and the musculature. The segmental arrangement of the embryonic vertebral column finds its counterpart in the similar arrangements of the musculature and the nervous system, so that when the development of the embryo is completed, all three systems, despite their complexities in the mature human form, can be derived from this primitive segmental or (to use the technical scientific expression) metameric arrangement of their components.

Blood vessels grow into all these organs as solid cords of cells, which then become hollow and filled with blood in order to supply the tissues with nutritive materials and oxygen. To keep the blood flowing through the vascular system a central pump, the heart, is developed [Fig. 24]. The section of the vascular tube destined to become the heart bends (a) and assumes an irregular S-shape (b). The walls of the curved portions come into contact (c), grow together, and the intermediary walls disappear (d), giving rise to the thick-walled heart, with its several chambers and passages, which pumps the blood through the vessels (e).

Triple Germ Layer

Thus a human being is developed from the egg-sperm cell of its parents. This cell develops into a cell sphere, the hollow sphere becomes a germinal disk, and from this triple-layered germinal disk develop the three

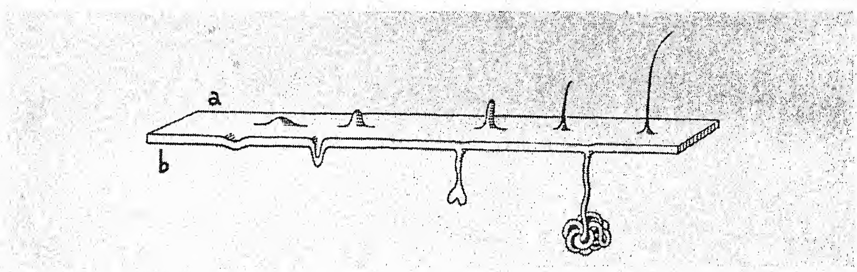


FIG. 22. *The skin sends out processes which become hairs (above), or which, by developing inwardly, become sweat and sebaceous glands (below).*

systems of the human body. This triple germ-layer system must be comprehended and remembered in order to understand the organization of the human body. In Figure 1 it is represented in its relations to the mature human body. Above we see the three germ layers at the moment when they begin to develop into the organ systems: (1) is the inner germ layer, from which the digestive system develops; (2) the middle germ layer, which gives rise to the bones, muscles, and blood vessels; and (3) the outer germ layer, from which the skin and the nervous system are derived. Below we see the human body separated into the three organ systems corresponding to the germ layers from which they have sprung.

Triumph of Research

This elucidation of the three germ layers and their relation to the structure of the body is the result of laborious research and endless scientific controversies over a period of many decades. But both the labour and the discussion were well worth while, for the theory of the three germ layers furnished a simple, clear, and easily comprehensible solution of the riddle of bodily organization.

The Biogenetic Principle. When we first survey the development of man, everything may appear clear and simple. The cell becomes a ball of cells; the ball, a hollow sphere; the sphere in turn is transformed into the flat germinal disk with two (later, three) layers. The lower layer gives birth to the alimentary tube, the upper layer to the neural tube and the integument; the middle germ layer differentiates to form the bones, muscles, and vascular system.

Unsolved Mysteries

The development of the human body from the combined egg and sperm actually takes place along the lines described above, but we should be doing nature an injustice and should retain an entirely false picture of the entire process if we omitted any mention of the fact that it is not really so simple as has been described. Indeed, it is far from simple, being in fact a very complex and, in certain

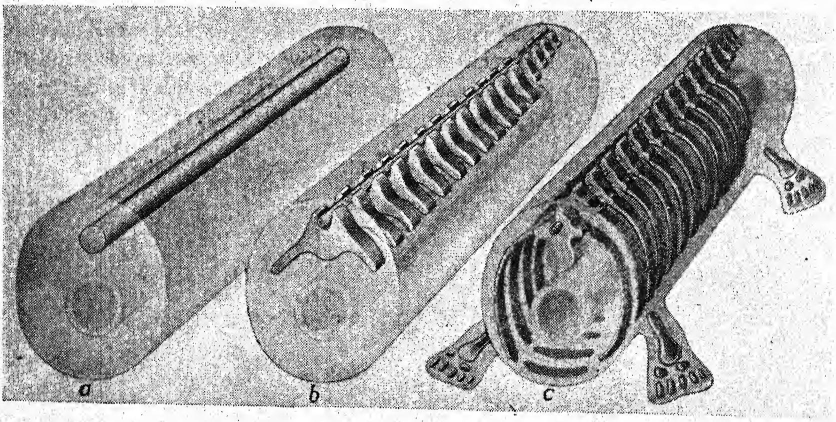


FIG. 23. *The formation of the skeleton. The axial rod (a) breaks up into the vertebræ (b), which then enclose the nerve tube and encircle the intestinal canal (c).*

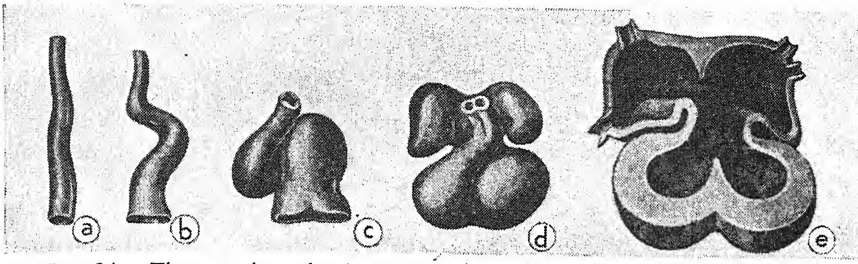


FIG. 24. *The vascular tube forms an S-curve from which the heart develops.*

respects, still undetermined process. Otherwise embryologists with all their scientific acumen would not have required an entire century of intense research and controversy to bring clarity into this subject and to unravel the fundamentally simple principles underlying the wonderful, one might almost say romantic, history of human development.

Complex Development

The complexity of human development becomes evident as soon as we recall that all the forces determining the developmental process reside in the extremely minute chromosomes, and that all forty-eight taken together are not one thirtieth as large as this dot (·). Within the insignificant-looking, grey human egg, which to all outward appearances differs from a caviar granule only in that it is one hundred times smaller, within this grey dot are contained all the factors determining the multitudinous variety of physical and mental characteristics of a future human being, characteristics derived in time from individuals and families of the most diverse kinds. Human development is indeed far from simple; it is rather a profound, obscure mystery.

When the sperm enters the egg cell, development begins, and proceeds according to a predetermined structural plan. One can very definitely say: The brain will develop from this part, the right eye will appear here, and so forth. And yet this apparent simplicity is deceptive. Human development is replete with unsolved mysteries, so that after obtaining a clear comprehension of the general principles of embryogeny it should not be forgotten that obscure problems still remain hidden behind this apparent clarity.

One of the most intriguing mysteries of embryonic development is connected with the phenomenon expressed in the "biogenetic principle": namely, that the developmental history of the individual is a brief, telescoped recapitulation of the history of the entire genus. While the hypothesis of the "biogenetic principle" is no longer accepted at present in the form first proposed by the biologist Ernst Haeckel, it still possesses a certain usefulness in that it enables us to understand some aspects of human embryology in relation to the evolution of animal life.

"Recapitulation"

In a sense we "recapitulate" the prehistory of the human race in our physical development before birth. This does not mean, however, that all the phenomena of human embryology are necessarily connected with the evolutionary history of man, but simply that the developmental

stages through which the embryo passes are in general suggestive of the history of the genus. Only on this

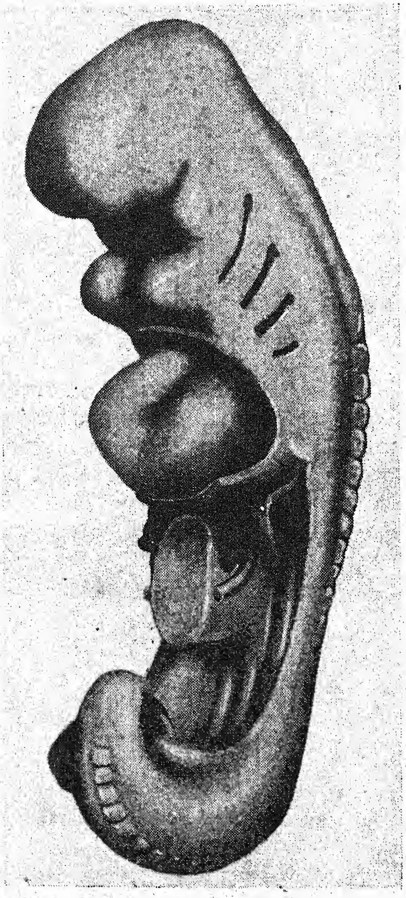


FIG. 25. *As a memento of its aquatic ancestors a twenty-day-old human embryo exhibits four gill slits in the neck.*

basis can we obtain some understanding of numerous incidental and transitional phenomena and processes that appear during embryonic development, quite contrary to the general principle by which nature strives to effect all that concerns growth and change in as direct a manner and as quickly as possible.

In the egg-sperm cell stage man is analogous to an amœba. It appears likely that all terrestrial life evolved from such a unicellular amœboid form. The next two stages of development, the mass of cells (morula) and the hollow cell-sphere (blastula) resemble many lower living things, both plants and animals, still to be found.

The process by which the two primary germ layers arise in lower animal forms is known as gastrulation, and consists in the conversion of the single-walled spherical blastula into a double-walled cup-shaped structure called a gastrula. The gastrula is formed by an invagination or folding in of one side of the blastula into its cavity. This process of gastrulation may be roughly compared with the pushing in of one side of a soft rubber ball. The resulting form resembles such animals as sea-anemones and jellyfishes. In mammals, including man, gastrulation is modified by the peculiarities of the human egg so that it is difficult to recognize any aspect of germ-layer formation resembling invagination. Nevertheless germ-layer formation in mammalian embryology may be regarded as being homologous with invagination in the development of lower forms.

Finally, the circumstance that during the nine months of intra-uterine life the human embryo "swims about" in a fluid medium appears to be both a recollection and an indication of the fact deduced from geological and palæontological evidence that the earliest forms of animal life were not terrestrial but aquatic [Fig. 26]. Apparently the ancestors of the dragon-fly, the mosquito, and the frog were also aquatic animals, for their larvæ still live in

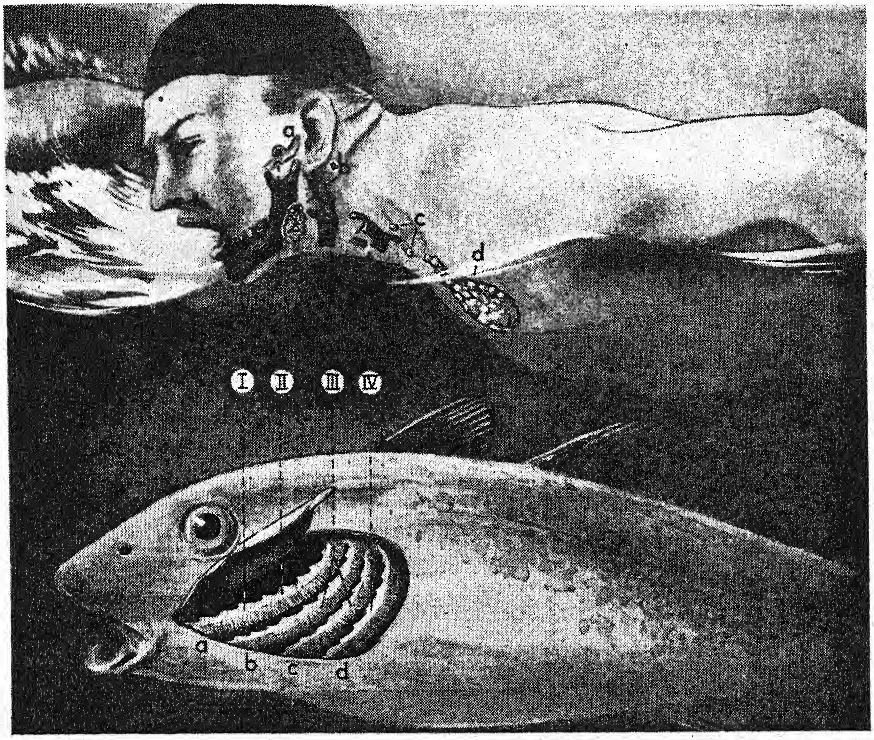


FIG. 26. *Human organs which are souvenirs of the gills of our fish-like ancestors. The figures (I—IV) indicate the gill pouches of the fish and the entirely different organs in man into which they have developed in the course of evolution.*

water, and their eggs are laid in it.

The strongest evidence for this assumption is the fact that on about the twentieth day of embryonic development four pairs of alternating depressions and prominences appear in the necks of all modern terrestrial animals, including the human embryo. These structures, known as the branchial grooves and arches, are homologous with the gill slits and bars in fishes—that is, with the respiratory organs of these animals [Fig. 25].

Viewed logically, the appearance of these structures permits of no explanation except on the basis of the biogenetic principle: namely, that they are relics of a time when the ancestors of man lived in an aquatic environment. In addition to tens of thousands of other hereditary factors, the chromosomes still contain genes from this " fish stage " in animal evolution. During the earliest stages of embryonic development, when the " human " genes have not yet completely unfolded their formative powers and supplanted the ancient primordial animal genes, the latter exert an influence for a short period and begin to form various organs. These organs no longer attain full development. They appear only in an incipient stage, never attain functional efficiency, and either disappear

without leaving any trace or are made over to serve some other function in the human body. A human being is not constructed like a modern office building, as cheaply, quickly, and

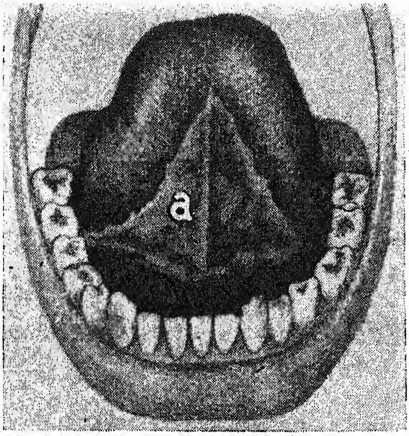


FIG. 27. *Vestigial organs are organs which have become superfluous; for example, the sublingual fold of the tongue (a), a relic of man's reptilian ancestors. Another example is the vermiform appendix.*

efficiently as possible on the basis of a good architect's plan, but rather like an ancient historic edifice to which wings and sections were added at different times and which was not modernized until it was almost completed. The old plan provided for gills, but today they are no longer needed. Since then we have moved on to the land, so the gill rudiments (the branchial structures) are transformed into new organs, just as on buying an old house one may have the woodshed rebuilt as a garage.

Degenerate Organs and Atavism. While the branchial arches and grooves are rebuilt, just as outmoded gas mantles are replaced by electric lamps, other structural souvenirs are deprived of their original usefulness while retaining their ancient form and remain as useless "family heirlooms" in various parts of the human body. These relics are known as degenerate organs. Examine the inferior surface of your tongue in a mirror [Fig. 27]. It will be observed that beneath the "modern" muscular mammalian tongue is a fold of mucous membrane, elevated to a distinct vertical fold in the mid-line, whose free edges exhibit a number of short fringe-like processes. This is all that remains of the older type of tongue still found in reptiles and amphibians, the kind of tongue with which snakes hiss and chameleons catch flies.

Malformations

Occasionally these degenerate organs do not remain satisfied with their roles as ancient heirlooms, but develop into complete organs, even though they no longer fit into the framework of the modern human body. They therefore appear as malformations. Numerous malformations in man are nothing but fully developed degenerate organs. Some children are born with neck clefts (cervical fistulæ) as a result of imperfect closure of the branchial grooves. In other cases nearly the entire body may be covered with hair. Such cases represent a persistence and continued growth of the first-formed hairs of the embryo that develop over the surface of the embryonic body and are designated as lanugo. Normally this souvenir of our animal ancestors is lost for the most part before birth. The lanugo hairs that are shed during intra-uterine life are found in the fluid with which the embryo is surrounded during this period. Since the embryo swallows large amounts of this fluid, lanugo hairs are also found in its intestine.

Among the many rudimentary structures that appear during embryonic life, the human embryo exhibits a tail or caudal appendage. This process represents the lower end of the vertebral column and is most prominent towards the end of the first month of fœtal life [Fig. 25]. Occasionally this appendage does not disappear as embryonic development progresses and the child is born with a rudimentary tail [Fig. 28].

Riddle of the Embryo

The mutual resemblance of all higher animals during the earliest stages of embryonic development is so great that they cannot be differentiated. Who can tell by simply looking at them which of the eggs in Figure 12 will become a plant, a starfish, or a human being? Cover the lower half of Figure 11 and ask any of your acquaintances to guess which embryo will develop into a horse, which will become a bird, and which one a lizard? No one will be able to give the correct answer except by chance. Not even a professor of embryology. In 1828 Karl Ernst von Baer, the famous founder of this science, wrote in his *Entwicklungsgeschichte der Tiere (Embryology of Animals)*: "I have two small embryos, preserved in alcohol, that I forgot to label. At present I am quite unable to determine the genus to which they belong. They may be lizards, small birds, or very young mammals." The Franco-American scientist Agassiz, a determined op-

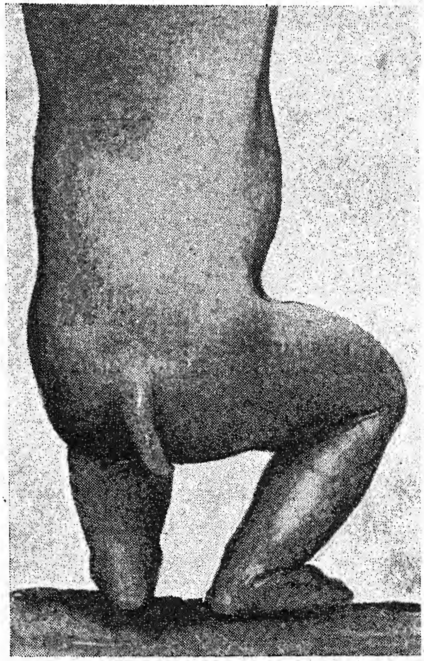
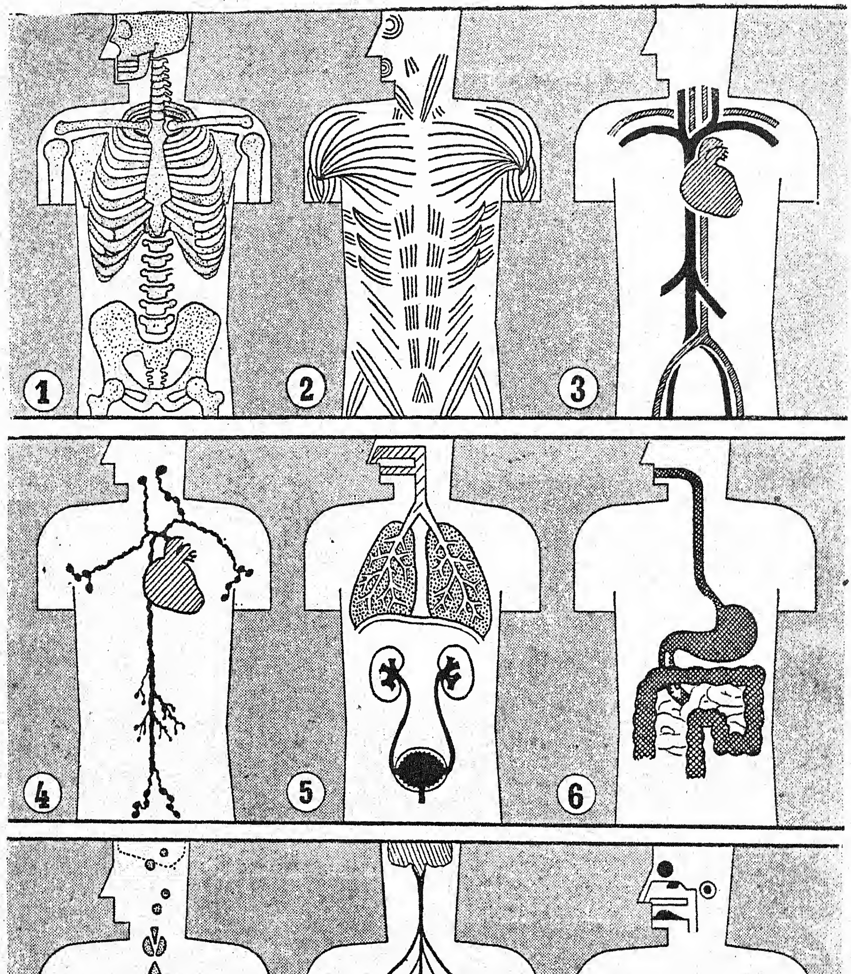


FIG. 28. *Atavisms or throwbacks are superfluous organs that appear in exceptional cases. This photograph shows an example of a tail in a human being.*

ponent of the Darwinian theory of the origin of species, had a similar experience. Having forgotten to label a certain embryo, he was unable to assign it to its proper place in his collection, much to his own discomfiture and the ill-concealed delight of his Darwinian colleagues.



THE ORGAN SYSTEMS OF THE HUMAN BODY

FIG. 29. *(1) The skeletal system; (2) the musculature; (3) the circulatory system; (4) the lymph system; (5) the excretory organs (lungs and kidneys); (6) the digestive apparatus; (7) the endocrine glands; (8) the nervous system; (9) sensory organs.*

CHAPTER III

Connective Tissue and Fat

CELL TISSUE. MUCOUS TISSUE. CONNECTIVE TISSUE. KEEPING CONNECTIVE TISSUE YOUNG. DISTRIBUTION OF CONNECTIVE TISSUE. ADIPOSE TISSUE (FAT) AND ITS DISTRIBUTION. FAT AS A FUEL, AS PADDING MATERIAL, AS INSULATING MATERIAL. FAT METABOLISM.

THE simplest structural element of a house is a brick [Fig. 30]. Bricks are used to erect house walls, and upon these in turn are constructed floors, ceilings, and subsidiary walls to form rooms. This structure, however, is not yet a house, but consists only of the bare brickwork.

Organizing the House

Doors and windows are required; the walls have to be plastered and papered; floor boarding must be laid and covered with rugs or linoleum; and finally the building has to be wired for lighting fixtures, as well as for bell and telephone systems, and plumbing must be installed for heat and water supply. But even now the house is not yet completed. The rooms thus constructed must be prepared for dwelling purposes. Groups of rooms have to be combined according to a definite plan. Thus an entrance hall, passage, living-room, bedroom, kitchen, and bathroom may be combined into a flat or maisonette. In a large block, still another group of rooms may be prepared as a store, a third group for office use, a fourth group as a cinema theatre, a fifth as a repair shop. The sum total of these different rooms and groups of rooms is the completed structure, the house.

The human body is constructed in an analogous manner. Its structural element is the cell. The cells are united, giving rise, in short, to the tissues of the human body — epithelial, muscle, gland, and nerve tissues. The tissues form the "rough brickwork." During the earliest stages of its development the embryo consists exclusively of tissues. Later, organs are created from the tissues. Corridors are laid and doors made. Warm-water pipes, as well as electrical wiring (nerves) to which all kinds of alarms (sense organs) are attached, wind along the walls.

The Organ Systems

One of the spaces developed becomes a workshop, another a storeroom, a third a photographer's studio like the eye, or a telephone receiver like the ear. The rooms within the house that have their own special arrangements and furnishings are known as organs. The heart, stomach, and kidneys are organs. Like the rooms in a house, the organs do not remain separate, but are

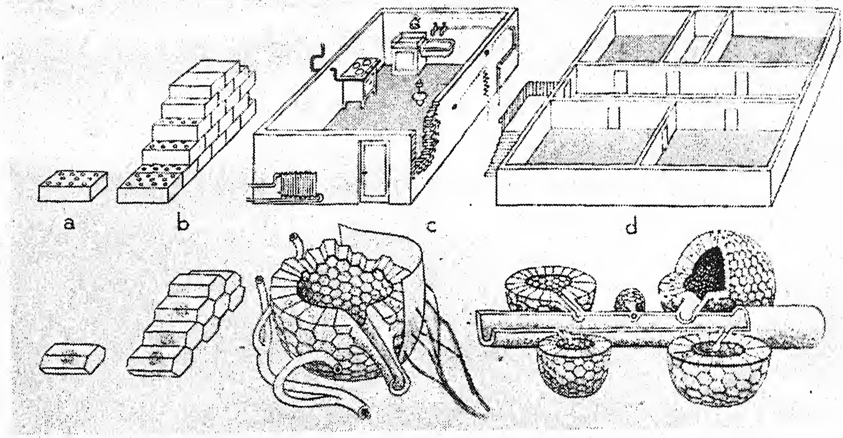


FIG. 30. *The body is constructed like a house. The cells, representing the bricks (a), are built up into tissues, which correspond to walls (b). The organs, grouped into organ systems, may be taken to represent rooms grouped into flats, (c) and (d).*

combined in "apartments." The "apartments" of the body are called organ systems, shown in Figure 29. Brick, wall, room, apartment are the structural units of a house. Cell, tissue, organ, organ system are the corresponding units of the body.

Mucous Tissue. Historically, the oldest and simplest tissue of the human body is of a mucous or gelatinous nature. It is probably the oldest tissue in the history of terrestrial animal life. The lower aquatic animals of primordial times, the sponges, sea-anemones, jellyfishes, and polyps, all consist almost exclusively of mucous tissue. During the first months of his embryonic history man is also a mucous creature. This tissue occurs in the umbilical cord, where it is known as the jelly of Wharton, but it does not occur anywhere in the mature human body. All embryonic connective tissue is at one period of this jelly-like nature. When examined under the microscope, this tissue is seen to consist of stellate cells connected with one another by a network of fibres, deposited in a clear semi-fluid substance [Fig. 31].

Connective Tissue. In the course of development the fibres grow longer and become separated from their mother cells, transforming the mucous tissue into fibrous connective tissue. Take some absorbent cotton, pick it apart, and strew some peas and peppercorns in the mass of fibres. The result is a model of fibrous connective tissue when magnified 100,000 times.

Figure 32 depicts the simplest organ of the human body, the peritoneum. When examined with the naked eye the peritoneum appears to be a thin rubber-like membrane which covers the walls of the abdominal cavity like wallpaper and has the function of maintaining the abdominal cavity moist, smooth, and warm. It is composed essentially of several superimposed flat layers of connective tissue. The nethermost of these layers (a) has retained its original character and is composed of

"loose" connective tissue. In the middle layer (b) the fibres are more prominently developed and have been felted together to form a firm fibrous tissue in which the cells lead but a modest existence. In the uppermost layer (c) the fibres have been pressed together so firmly that they form a homogeneous-looking glassy membrane. The loose connective tissue corresponds to absorbent cotton; the firm, tough connective tissue resembles a carpet; the glassy tissue, a sheet of paper. Take this page between your fingers and feel it. This paper is also composed of fibrous connective tissue, which has been compressed into a "glassy membrane" as a result of being subjected to various chemical processes and pressure. In the body one finds all types of connective tissue from the equivalents of the finest cotton and tulle to that of coarser materials, including the coarsest leather. Indeed, leather is nothing else but the treated connective tissue of an animal skin. Parallel skeins of connective-tissue fibres plaited together form tendons, ligaments, certain membranes, and the capsules of various organs of the body. Owing to the ingenious manner in which the fibres are interwoven, these structures possess great strength. The pelvic ligaments that join together the trunk and the thighs are so strong that they will bear a load of over 880 pounds. Indeed their strength is so great that one might even undertake without trepidation a balloon trip in a gondola which was connected with the balloon by no other means than a human pelvis and supported only by the pelvic ligaments.

When connective tissue is boiled, the fibres dissolve, forming a sticky protein, gelatine. Joiner's glue is the gelatine obtained from the connective tissue of bones by boiling them. When bones and pieces of meat are cooked in water, a light-brown solution of gelatine is obtained, bouillon. This fluid contains not only gelatine, but also the savoury and aromatic "extractive

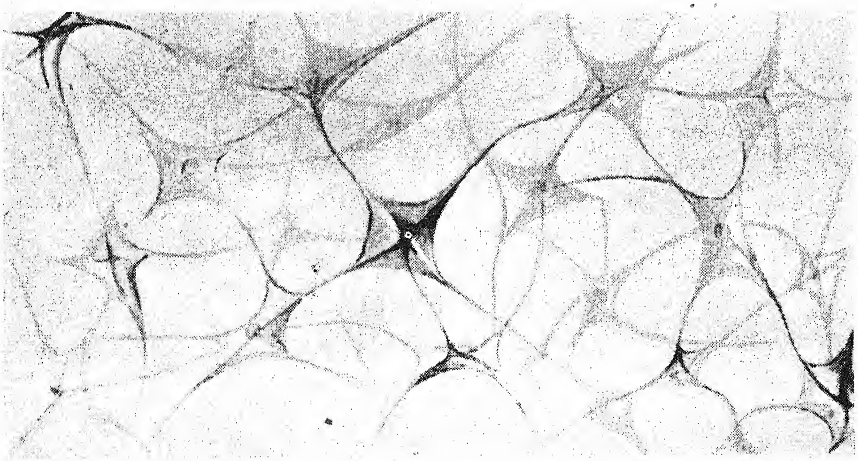


FIG. 31. *The gelatinous connective tissue, shown above (magnified), is historically the oldest and simplest tissue of the human body.*

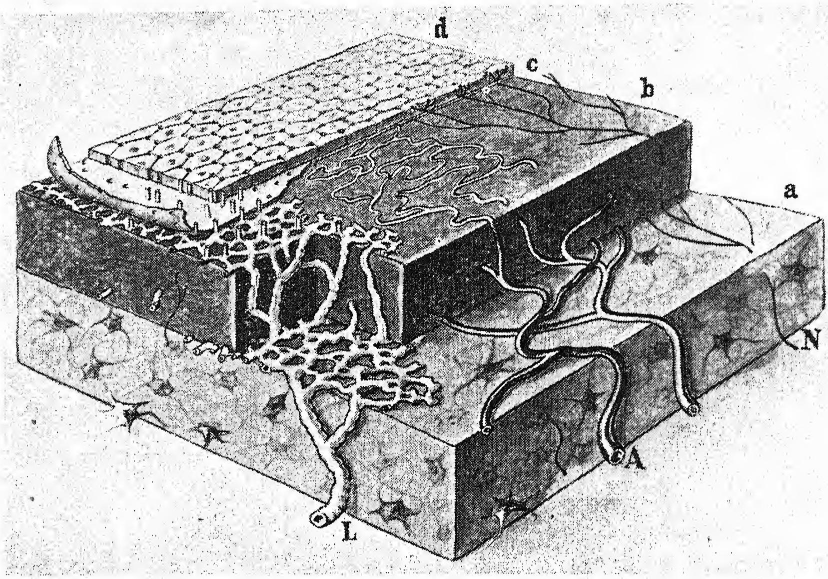


FIG. 32. *The peritoneum, an elastic membrane which lines the walls of the abdominal cavity, is the simplest of all organs. It consists chiefly of connective tissue, arranged in three layers (a, b, c) and covered by a layer of epithelial cells. Networks of lymph-vessels (L), blood vessels (A), and nerves (N) are situated between the connective-tissue layers. Through the terminal openings of the lymph-vessels flows the abdominal fluid, which moistens the pelvic organs and keeps them smooth.*

salts" of the meat and bones. Meat broth is a solution of gelatine combined with extractive substances.

Old connective-tissue fibres are indigestible. For this reason meat, especially old meat, is beaten to make it tender, because this process causes the fibres to tear. For the same reason meat is placed in vinegar or sour milk because the fibres are attacked and dissolved by acids. Young connective-tissue fibres are as elastic as rubber bands. Lift a fold of skin on the back of your hand and then release it: the connective-tissue fibres recoil, pull the skin back to its original position, and the fold disappears. The elasticity of the connective-tissue fibres in the skin is the secret of a youthful appearance. A machine becomes worn out and inferior after it has been used for some time; it becomes second-hand. It is quite the contrary with living creatures. They accomplish least at the beginning of their careers and attain the peak of their capabilities only after a long period of hard work and training.

When we are speaking of a new machine we say: "It works perfectly"; but of a young boxer or pianist: "He has possibilities if . . ." This "if" means: if he is capable of developing his youthful machinery by means of hard work and training so as to make the most of his talents and potentialities. Unlike an inanimate machine, an organism is not worn out by activity, but on the contrary attains the peak of its productive powers by regular and judicious use.

What is true of the entire body is valid for each of its parts. Joints must be used in order to remain supple. Too much rest makes them "rusty." Muscles must be exercised daily—indeed, almost to the point of exhaustion—so that they will become powerful and attain their maximum development. As soon as exercise ceases, muscular function becomes impaired. The kidneys are not injured by the fact that they must carry out the complex process of filtering the blood uninterruptedly for a period of seventy years. The brain is not impaired by mental activity and experience; on the contrary, poets, thinkers, and inventors often astound us by the productivity of their mental powers in old age.

Creative Old Age

Æschylus went on writing plays as an old man, Titian painted until he was ninety-nine, Voltaire died at a ripe age in the midst of triumphs, while Goethe, Wagner, Tolstoy, and Edison were still in full possession of their intellectual powers when they attained the natural and ultimate goal of human life after sixty and seventy years of mental activity. The principle of exercise is valid for man: the body attains and retains the maximum development of its capacities only by continuous and judicious exercise.

Keeping Connective Tissue Young. Each connective-tissue fibre in our skin is a minute but independent vital unit that "wants" to breathe, eat, rest, and exercise daily in order to remain healthy. Correct care of the connective-tissue fibres is the best beauty remedy known to the cosmetic art. The connective tissue as well as the entire skin should receive an appropriate healthful diet; the entire body should have adequate periods of rest (sleep and holidays) depending on the season of the year; and, above all, the connective-tissue fibres must be exercised daily. This may be accomplished by skin massage. The kneading of the skin prevents sluggishness or spasticity in the vascular system and maintains it functionally active. The massaging of the skin also presses various waste products out of the ducts of the skin glands. The care of the skin must naturally start very early. Young tissues can be kept functionally fit, but old tissues cannot be rejuvenated. One should not succumb to any illusions on this subject. While the process of ageing may be retarded, youth, once gone, cannot be retrieved.

The Distribution of Connective Tissue in the Body. Connective tissue is the most widespread tissue of the body. From the middle germ layer, situated in the middle of the developing embryo, the connective-tissue cells proliferate and spread into all the interstitial spaces of the growing organism.

Protective Packing

It is their function to fill all the corners and spaces, as if with soft cotton, and grow over the surfaces of organs, thus becoming their capsules. When the human body is completed all the parts are enclosed in connective tissue and packed like chinaware in a box. All the cells lie in connective-tissue containers like eggs packed for shipment or like bricks in a wall surrounded by mortar. Just like the individual cells, the organs as a whole are encased in connective-tissue coverings and suspended by ligaments. The brain is covered by an ingeniously woven

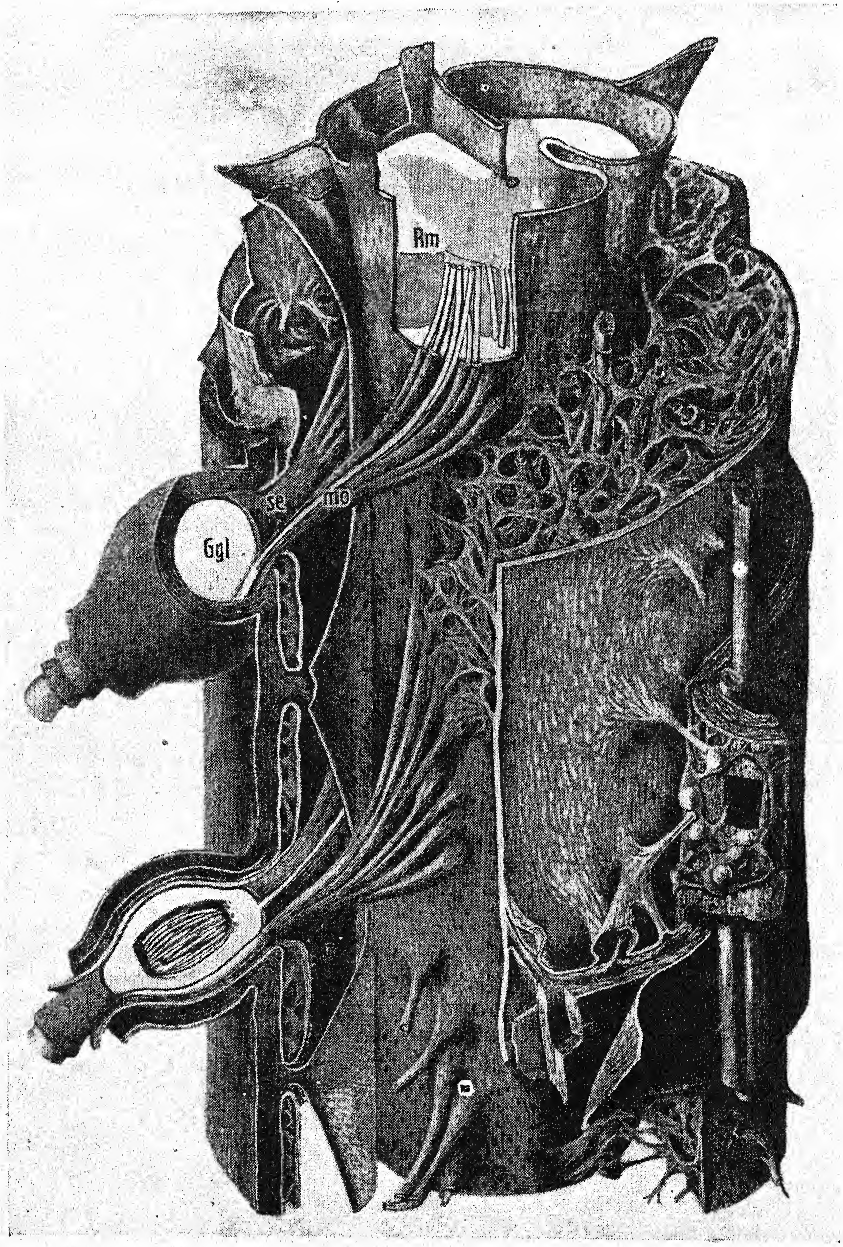


FIG. 33. *The spinal cord (Rm) with the ganglia (Ggl) and the sensory (se) and motor (mo) nerves wrapped in the various layers and networks of connective tissue. All the organs of the body are very carefully packed in connective tissue, just as we pack delicate porcelain, so that they will not be injured by abrupt or jarring movements.*

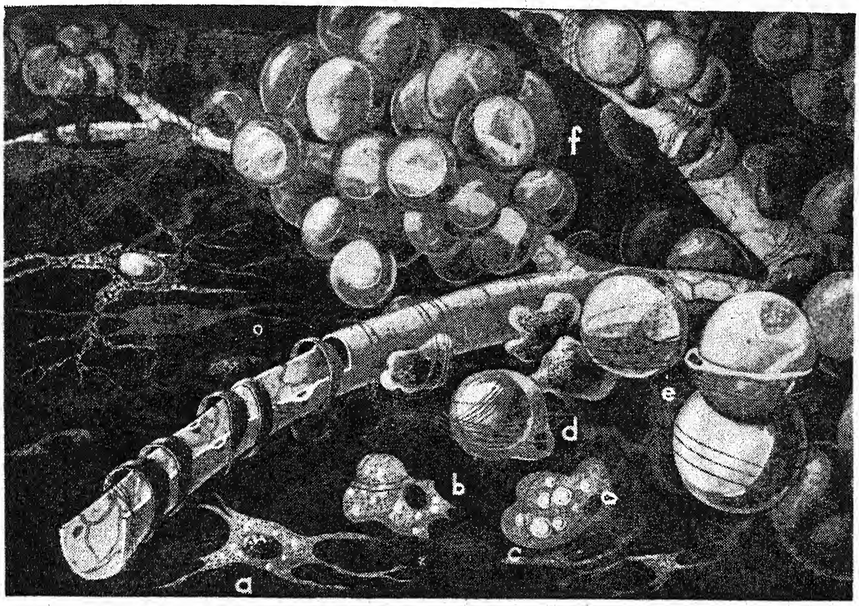


FIG. 34. *Fat tissue is formed from connective tissue. The cells (a) to (e) show progressively the transformation of a connective-tissue cell into a fat cell. Droplets of fat collect in a connective-tissue cell, ultimately filling and distending it. The fat cells arrange themselves eventually around the blood vessels in grape-like clusters (f).*

capsule called the dura mater. The spinal cord is enclosed in a connective-tissue cover like an umbrella in its case [Fig. 33]. Each bone and each joint is wrapped in connective tissue, and each muscle is enveloped in a strong sheath of the same material, as if it were covered with a sock, within which the muscle moves back and forth like the piston of a steam-engine [Fig. 97].

If it were possible to macerate a body so that all the parts except the connective tissue would disappear, we should see a framework with innumerable chambers, a giant cocoon, the mortar framework of the human house.

Fat Tissue and its Distribution. At certain points within the human body these connective-tissue cells become filled with fat. At first tiny droplets appear within the cells. These increase in size, run together into a large drop, finally filling the cell and swelling it out like a balloon, so that the cell is eventually transformed into a large drop of fat surrounded by a thin envelope of cytoplasm [Fig. 34, (a) to (e)]. Since the fat is transported to the cells by the blood, it is pre-eminently the cells in the neighbourhood of the blood vessels that are transformed into spherical fat cells. Ultimately masses of these cells collect around blood vessels like grapes on a stem (f). If a majority of connective-tissue cells has been transformed into fat cells the tissue is called adipose tissue.

Ears, nose, forehead, and joints are normally devoid of fat tissue. Fat accumulates chiefly in the subcutaneous connective tissue, in the cover-

ings of the intestines and in the mesentery within the abdominal cavity, in the pelvic region on the hips and buttocks, and in the female breasts. The storage of fat is greater in the female body than in the male. This does not occur by accident or voluntarily, but apparently owing to the influence of the female sex glands, the ovaries. As soon as a young girl becomes sexually mature, her body begins to accumulate fat in certain specific regions, above all in those parts of the body intimately related to the development, care, and protection of the child—that is, the pelvic region, where the child lies during pregnancy, and the breasts, at which it is fed after birth.

Change of Life

With the appearance of the "change of life" and the beginning of the ageing process, the ovaries cease to produce egg cells, and the reserve deposits of fat disappear. The breasts become flaccid and dependent, and the buttocks again assume a narrow, childlike form. At least, that is what should happen according to all the laws of logic, and does indeed take place in truly healthy women. Actually, however, many women become obese during the "change of life" with the cessation of ovarian function. The deposition of fat in this type of obesity is quite different from the accumulation of adipose tissue during adolescence, which produces the budding beauty of maturing young women. Excessive accumulation of adipose tissue always tends to occur whenever the oxidative energy of the organism is not great enough to consume completely the ingested food and to use it in the body. In contrast to the healthy formation of fat in the normal body, the condition characterized by an abnormal deposition of fat is designated as obesity.

The normal male body contains approximately ten per cent fat, that of a normal female somewhat over twenty-five per cent. A comparison of the body of a well-developed young man (120 pounds) with that of a young woman of equal weight shows that the male body contains about 13 pounds of fat, the female body about 35 pounds.

Fat as a Fuel. The primary function of fat in the body is to serve as a food reserve. It is especially suited for this purpose because fat is the best and most concentrated fuel that we know. It is only during the last few decades that technology has begun to employ heavy oils as fuels for motors, locomotives, and aeroplanes. This method of fuelling had long since been introduced by living organisms. The human body uses three fuel materials to drive its machinery: (1) protein, (2) carbohydrates—that is, sugars and starches, (3) fats. The normal daily fuel of the human body is sugar, which is obtained from the starches of flour, potatoes, vegetables, etc. Sugar is preferred because it burns very easily, perhaps as easily as paper or wood. Fat burns with difficulty, but it has the advantage of producing much more heat than an equal quantity of sugar. At a matter of fact, weight for weight, fats have about twice the energy value of carbohydrates.

The Body's "Reserve Capital"

Owing to its high energy value and the difficulty with which it burns, fat is especially suitable as a storage material and fuel reserve, and is therefore deposited in the body for this purpose, to be used as needed.

A healthy person maintains his fat supply unchanged for many years, just as a solvent, well-managed business does not touch its reserve capital, or as a well-supplied house has a reserve store of coal laid away in a coal-bin for any emergencies. If an individual's food intake is too small for the body's needs, he attacks his fat reserves and grows thin. Emaciation is a sign that the fat reserves of the body have been diminished.

Fat as a Padding Material. The second function of fat is to serve as a padding material. The fat-filled connective-tissue cell is a spherical envelope of protoplasm filled with fat; in other words, it is a microscopic water-cushion, with all the advantages of one. It cannot be compressed, because of its resiliency. Adipose tissue is a padding material composed of water-cushions, perhaps the best that technology has yet devised. The buttocks are "water-cushions" with which nature has equipped us for sitting. Consequently a healthy person, in contrast to an emaciated one, needs no cushion to sit on. A second pad of this kind is situated under the arch of the foot. Its function is to absorb the shocks of walking, in a manner similar to the air-cushions of the pneumatic tires of our automobiles.

Protective Lining

A third such pad lies underneath the skin of the palm of the hand, as a kind of natural glove-lining protecting the nerves and blood vessels against pressure and cold. A fourth pad is situated in each cheek, and acts here as a suction pad during the acts of eating and drinking. Yet a fifth one fills the orbital cavity and provides a soft cushion on which the eyeball lies and rotates during its movements. If an individual becomes emaciated as a result of illness and his fat pads vanish, he can no longer sit for any length of time without cushions, his feet hurt when he walks, his cheeks become hollow and his eyes cavernous. Thus illness indicates to us the distribution and significance of fat tissue in the healthy body.

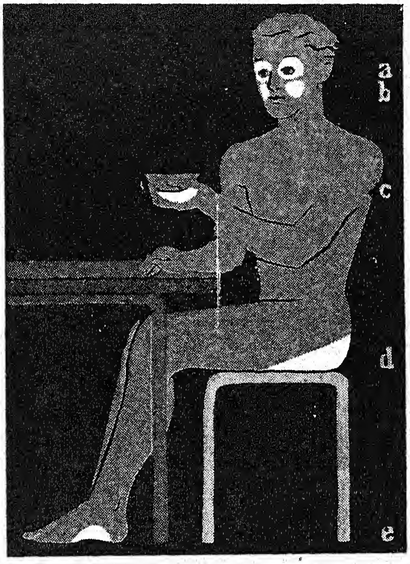


FIG. 35. *The mechanical fat pads of man. A human being has a pad of fat for sitting (d); for standing (e); for holding (c); and for sipping (b). In addition the eyes rest on a thick pad of fat tissue which acts as a ball-bearing during rotation (a).*

Fat as an Insulating Material. The third function of adipose tissue is to serve as an insulating material. Fats and oils are poor conductors of heat and electricity, and consequently excellent insulating materials. In electrical engineering, oil is employed as an insulating material in apparatuses using power currents. The nerve apparatuses and conduction systems of the human body are

embedded in a special nerve fat. When deposited in thick layers, fat is an excellent protection against heat loss. Polar animals, such as whales, seals, and aquatic birds, all possess thick layers of blubber and are consequently the chief sources of animal fats. Even when nude, man wears a thick oil coat under his skin, in the form of subcutaneous fat tissue. It is the best protection against cold that we have. A thin person freezes easily because his oil coat is too thin, while an obese one perspires because the heat produced by the body collects under his fat layer faster than it can be dissipated.

The Regulation of Fat Digestion. Within the body, fats are digested in the small intestine by the pancreatic juice. The activity of the pancreas is economically accommodated to the digestive needs of the individual. Pavlov showed that the production and composition of pancreatic juice at any time varies with the quantity and character of the ingested food. This means that a meal rich in fats will call forth a pancreatic juice containing a higher concentration of fat-digesting substance than a meal rich in carbohydrates.

Excess of Fat

Undigested fatty food is not absorbed and passes through the intestinal canal and is eliminated with the fæcal matter. When children are overfed with milk, their stools contain an excess of fat. These stools are greyish white in colour, resembling a mixture of chalk and soap, and are called " soap " stools.

Fat Metabolism and Obesity. From the intestine the digested fat is carried to the tissues and deposited there. If the deposited fat is required at any time for fuel, it must be taken out of the tissues like coal from a coal-bin, or, as expressed in scientific terminology, it must be mobilized. This mobilization is carried out by means of the secretion of the thyroid gland. This gland, weighing about one ounce, lies in the neck on the sides of the windpipe and supplies a substance containing iodine, a hormone, to the blood-stream. If thyroid hormone is administered to an organism, it loses weight rapidly and becomes thin. If the thyroid gland is hyperactive and produces an excess of hormone, as in hyperthyroidism (Graves' disease), the affected individual becomes emaciated, leading finally to a serious condition of extreme weakness.

Dangers of " Reducing "

On the other hand, if hormonal production is diminished, an excessive deposition of fat in the tissues is the result. Thyroid hormone would be an ideal reducing remedy were it not so toxic. In view of this circumstance, however, it should be used only under the supervision of a physician and then only for short, precisely determined periods. Many secret reducing remedies contain this effective but highly toxic hormone and should therefore be regarded with the greatest suspicion. Naturally, thyroid hormone can be of use only when obesity is due to a deficiency of thyroid secretion.

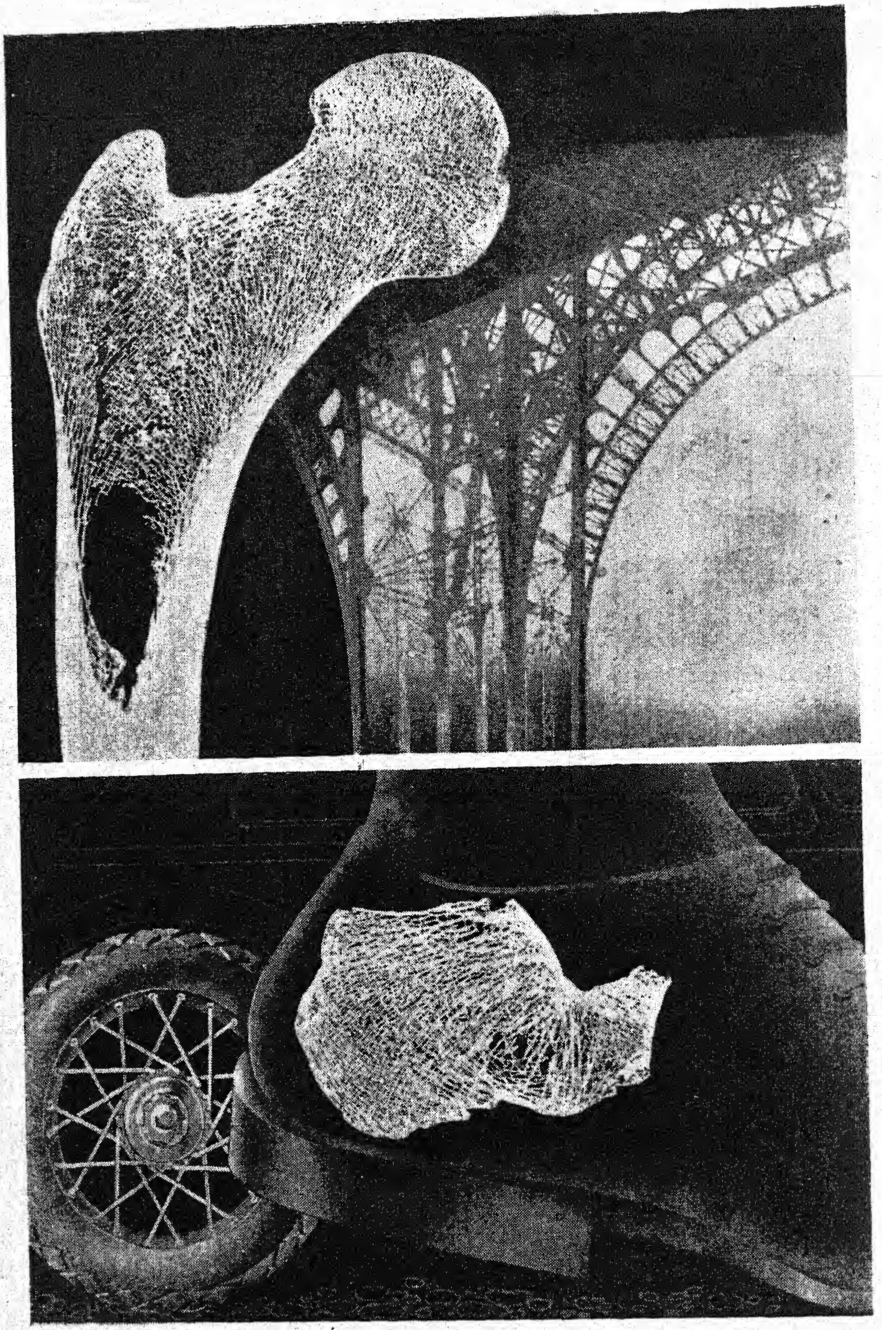
Other types of obesity may be the result of climatological, geographical, or perhaps evolutionary influences. It is generally known that the women of the Near East tend to obesity. The female Hottentot is remarkable for an excessive deposition of fat in the gluteal muscles, resulting in enormously obese buttocks, a condition known as steatopygy [Fig. 36].

Adipose tissue, the organ of fat storage, is a relatively inert tissue. A thin person uses up 3.6 cubic centimetres of oxygen per minute for every kilogram (2.2 pounds) of body weight; an obese person consumes only 2.8 cubic centimetres, almost twenty-five per cent less. Excess fat is a dead load for the body. An obese person may be compared to a handicapped racehorse. Not only does the unnecessary burden encumber his joints, but it also throws an extra load on his heart. Adipose tissue is quite vascular, being well supplied with blood vessels, so that the heart must pump the blood through all these vessels. Because of the presence of the fat tissue the body becomes over-heated, and consequently, in order to cool it, the heart must transport unnecessary quantities of blood to the periphery, where the heat may be dissipated through the skin. An obese body is less resistant to disease. During epidemics the mortality is greater among obese individuals than among lean ones, and a fat person has less chance to achieve a patriarchal age.

FIG. 36. *The excessive accumulation of fat in the gluteal region is considered a mark of beauty among the Hottentots and certain Negro races of Africa.*

Obesity and Character

The burden of fat affects not only an individual's physical mobility but also his character. Obese people are generally good-natured, tend to be phlegmatic, and rarely make the front page of history. Don Quixote is as thin as a lath, his lazy servant is named Sancho Panza (Full Belly); Till Eulenspiegel is as slender as an acrobat, his phlegmatic companion answers to the name of Lamm Goedsack (Pious Goodbelly). Cassius, the leader of the conspiracy against Cæsar, "has a lean and hungry look," and Cæsar rightly says: "Let me have men about me that are fat; sleek-headed men and such as sleep o' nights. . . . Would he were fatter! . . . I do not know the man I should avoid so soon as that spare Cassius."



HOW BONES COMBINE LIGHTNESS WITH STRENGTH

FIG. 37. *The bones contain small supporting girders, situated along the lines of strain and stress, exactly like the supports of man-made structures. The thigh-bone (Above) is a supporting tower, the heel-bone (Below) is a wheel with spokes and a felloe.*

CHAPTER IV

Cartilage, Bones, Joints

CARTILAGE. OSSIFICATION. GROWTH. THE ARCHITECTURE OF BONE. BONE-MARROW. CALCIUM AND GELATINE. FRACTURES OF BONE. THE JOINTS. SPRAINS. DISLOCATIONS. TREATMENT OF INJURIES.

AT those points where connective tissue is subjected to powerful stresses and strains, the fibres under the influence of these forces come close together and form a translucent homogeneous substance called cartilage. If cartilage is examined under the microscope, the cells of this tissue are seen as spheroidal bodies embedded in an amber-like matrix [Fig. 38].

Formation of Bone

At first the skeleton consists exclusively of cartilage. At parturition the bones are still so soft, owing to their large cartilage content, that the child can withstand without any harm all the acrobatic distortions to which it is subjected during the act of birth. Almost every infant falls out of its nurse's arms or out of its crib at least once—without suffering any harm. Indeed, it is even possible for children to survive a fall of several storeys without broken bones — thanks to their "guardian angel," the partly cartilaginous skeleton.

Ossification. The process of bone formation is initiated by a growth of blood vessels into the cartilage, which is avascular. These vessels grow into the central portion of the cartilage. They are accompanied by young connective-tissue cells that absorb the matrix surrounding the encapsulated cartilage cells. In Figure 39 this process is depicted as a battle between two groups of human beings. The blood vessels penetrate from the left. With them, as warriors conveyed in small boats, come the connective-tissue cells, and advance against the cartilage cells. The latter "defend" themselves by entrenching behind firm capsules, multiplying, and deploying in straight lines of battle. However, the connective-tissue cells conquer. They disrupt the capsules and occupy the captured positions. The vessels supply them with calcium, which they mix with the amber-like gelatinous matrix of the cartilage to form bone substance.

How Bone Grows

The cartilage cells withdraw and take up a new position. This retreat of the cells lengthens the cartilage at each end. Each individual cartilage is lengthened; the skeleton becomes longer and larger, and with it the entire person. In other words, the individual grows.

Ossifying cartilage, however, grows not only in length, but also in breadth. Some of the blood vessels do not penetrate into the substance of the cartilage, but grow along its outer surface. The connective-tissue cells erode the substance of the cartilage, mix the eroded material with

calcium, and with this mixture build tubes, pillars of bone, that become the external walls of the growing bone. As a result of the internal process the cartilage becomes longer; in consequence of deposition on the surface it becomes thicker and stronger.

Growth. Growth is one of the many important problems of biology and is still a chapter full of mysteries. Let us consider this subject. Here is a child. It is two feet high and so small that it can be put into a baby-carriage. In the course of eighteen years this child will develop into an individual three times as tall, with fifteen times as much body substance. It increases in size, while at the same time it changes in both character and appearance, becoming an entirely different person. The individual notices relatively little of this internal and external alteration [Fig. 40]. Try to imagine the look on an architect's face if we were to ask him to make our house three times higher and wider than it is at present without disturbing our daily labours or night rest for one hour. Nature solves this problem very ingeniously and, like an achievement of genuine genius, in simple fashion [Fig. 41]. Each day a minute trace of material

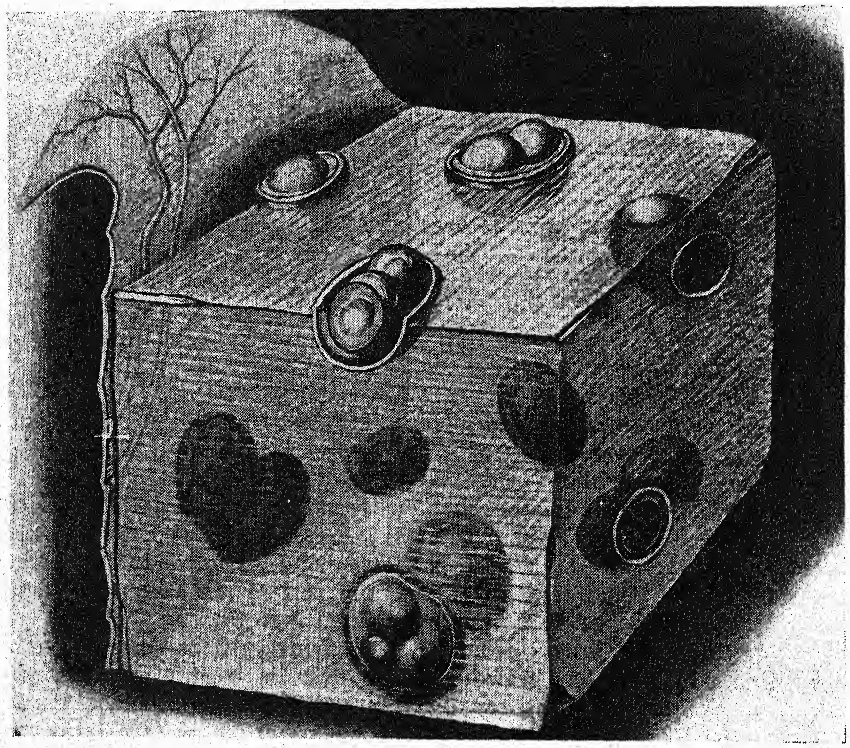


FIG. 38. *Cartilage is an amber-like mass produced from connective tissue. In order not to become compressed, the connective-tissue cells have surrounded themselves with capsules, in which they live like mussels in their shells. A newborn infant's skeleton is composed of cartilage. Later, most of the cartilage is transformed into bone.*

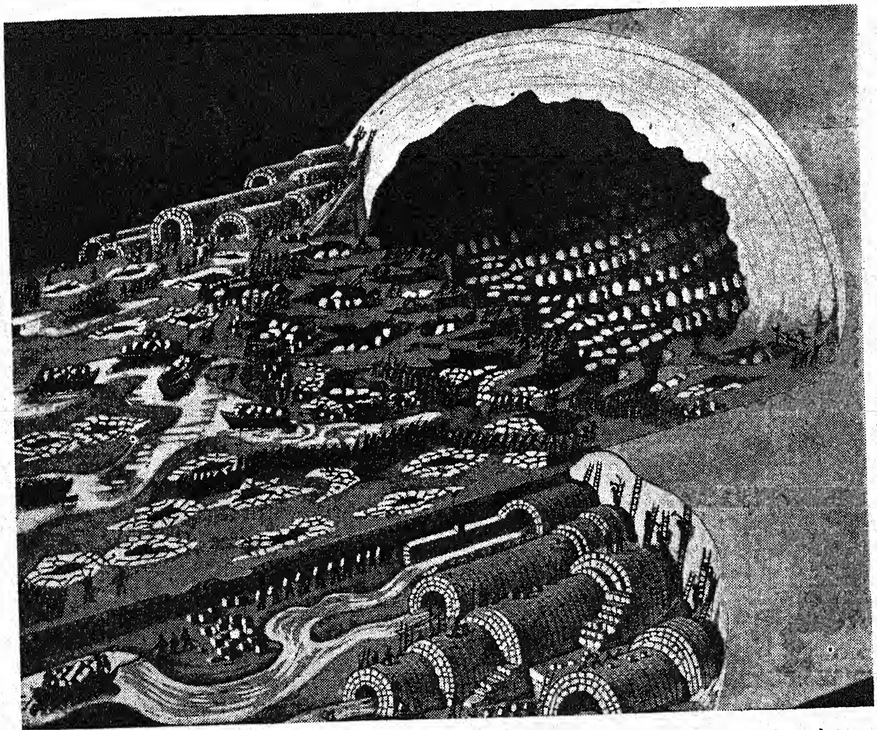


FIG. 39. *Bone formation depicted in the form of a battle. Blood vessels advance from the left against the cartilage on the right, bearing young connective-tissue cells (warriors). The cartilage cells armour themselves with white plates of calcium, but are defeated and flee. This cell flight is the growth process. The inner portion of the bone contains the "debris" of the battle; the outer wall is constructed by the "bone-builders" out of the blood vessels, collagenous fibres, and calcium (foreground).*

is scraped from the walls of the inside rooms. This substance is carried off and applied to the walls externally. The ceilings are treated in the very same manner. A little material is scraped from the ceiling daily, carried up to the next flight, and spread on the floor of the upper apartment. In this manner the walls extend outward and the ceilings upward. Each week the room grows several millimetres larger, and in twenty years the house is three times as large. In the body this mason's work is performed by special cells known as osteoclasts (bone - breakers) and osteoblasts (bone-builders) [Fig. 41].

The skeleton does not ossify completely. Certain parts remain cartilaginous—the tip of the nose and the external ear, because they would probably break off if they were bony; portions of the ribs, because the thorax must remain elastic during respiration; the larynx and the windpipe (trachea); and finally all those places where moving bones impinge on one another—that is, the joints. The ends of the bones remain covered by soft articular cartilages, and between these, in some instances, lie still other special cartilaginous

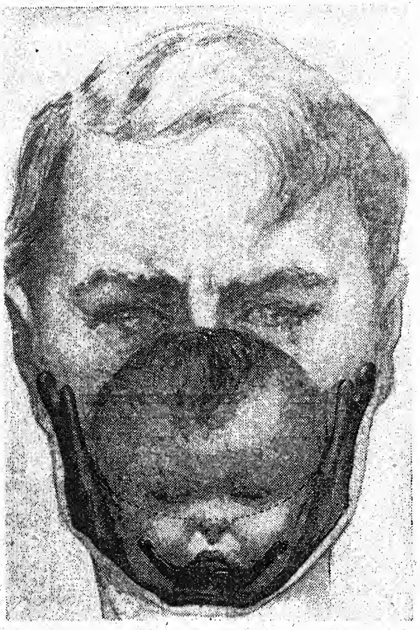


FIG. 40. *Question: How does the body set about enlarging the small bones of the child until they attain adult size, without disturbing vital activities of the body?*

disks that prevent the bones from coming into contact too abruptly with one another in walking or jumping. They act like the buffers between railway cars, or like the springs between the body and the chassis of an automobile.

The length of the ossification period of the skeleton, or, what amounts to the same thing, the duration of the period of growth, bears a fairly definite relation to the duration of life. In most higher animals this proportion is as 1:6. Rabbits, dogs, horses, camels, and elephants live six times as long as their growth periods. This rule is only approximate, however, and exceptions to it are far from rare.

The Architecture of Bone. The "struggle" between bone and cartilage as depicted in Figure 39 resembles a twofold attack on a beleaguered city. One group of attackers has entered the interior by way of a subterranean path and is engaged in a struggle with the inhabitants in the streets of the city. The other group besieges the cartilage from outside, blocks the gates with brickwork, and lays a ring of bone about the cartilage. After its completion bone clearly exhibits its origin in these two processes. The interior of the bone [Fig. 39 (*Centre*), Fig. 37 (*Above*)] contains the remains of a "battlefield." The firm outer wall of the bone, however, is the product of an annular accretion of layers of bone substance [Fig. 39 (*Foreground*)].

Lines of Pressure

In a young bone the cavity in its body is filled with a chaotic mass of small cell fragments and spicules of bone substances, the remnants of the previously described cell struggle. During the period of childhood, however, these fragments arrange themselves like iron filings in a magnetic field of force. As soon as the child begins to walk, the bones must support it, with the result that they are subjected to pressure. This pressure is exerted along definite lines, the static thrust-lines. The fragments that lie along the course of these static lines are put under a strain and stimulated to grow. They grow together with the bone so that the bone fragments remain situated along the lines of pressure. Fragments that are not located along the lines of pressure, and consequently receive no growth stimuli, remain weak, do not keep up in their growth with the rest of the bone, and finally disappear when the network of

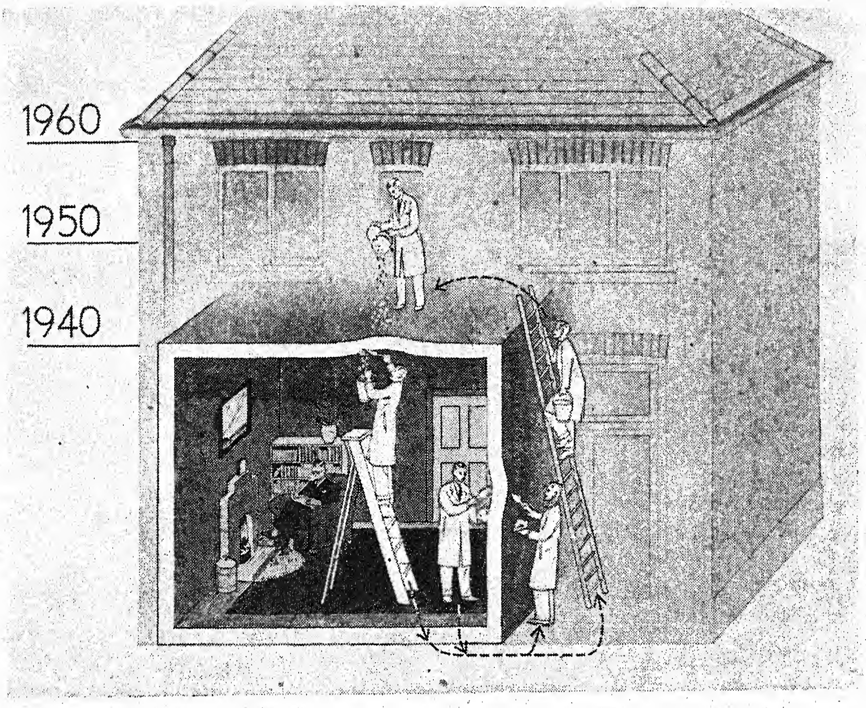


FIG. 41. *Answer: Cells called bone-breakers gnaw uninterruptedly at the internal wall of the bone and remove it. This substance is then replaced on the outer surface of the bone wall by bone-building cells. In this way the bony walls extend outwards almost imperceptibly. The house enlarges itself without disturbing its inhabitants.*

spongy bone has grown larger and stronger [Fig. 37]. Imagine the case of a bridge-builder who constructs a bridge along very massive lines. He then observes that only certain parts actually bear the weight of the bridge and its load and that therefore they alone are functionally necessary. He leaves these parts in place and removes those that sustain no pressure. What is the result? He obtains a bridge structure built of supporting pillars, located precisely along the static lines of pressure. Our architects proceed in exactly the same manner, but they do not go to the trouble of first erecting a massive structure. Instead they determine the static lines theoretically and construct our modern bridges on the basis of these determinations. The striking correspondence between the construction of such bridges and the structure of certain bones in our bodies is shown in Figure 37. In the heel-bone, which " rolls " along the ground, the bony network assumes an arrangement very similar to that of the felloe and spokes in a wheel [Fig. 37 (*Below*)]. In the vertebræ, which are united to a column, the minute bone " girders " are arranged in horizontal and vertical positions; while in the curved portion of the hip-bone, upon which the trunk is balanced, their arrangement

resembles that of the framework of an arch [Fig. 37 (*Above*)].

In contrast to the architecture of the spongy interior of bone, its outer wall consists of compactly arranged material. The outer wall of bone is produced by the blood vessels and connective-tissue cells that undertook to besiege the cartilage from outside [Figs. 39 and 42]. Each vessel (f) has surrounded itself with a corona of connective-tissue cells (d), which have enclosed it in layers of bone substance (e). The totality of these layers forms the bone lamellæ; and the unit composed of a blood vessel, connective-tissue cells, and bone layers is known as a bone or Haversian system (a). An individual Haversian system is no thicker than the point of a needle. The wall of the thigh-bone [Fig. 37 (*Above*)] is composed of 30,000 such systems.

Birthplace of Blood Cells

Bone-Marrow. The outer layers of all bones are compact. In long bones, however, the inner portion in and near the middle is hollow and filled with a soft, spongy tissue, the bone-marrow. Look at the inner portion of a soup bone; the reddish-yellow, gelatinous mass, which is regarded so highly by housewives because of its "strength," and by gourmands because of its peculiarly delicate taste, is the bone-marrow. Although the opinion of housewives is not based on scientific knowledge but more probably on experience, it is nevertheless correct. Bone-marrow does contain "strength," for it is in this tissue that the cellular elements of the blood are formed and developed. Indeed, the bone-marrow might be called the mint of the cell state. A billion new blood cells are coined and issued here daily and then dispatched by way of the vessels in the bone wall into the circulation. As the birthplace of the blood cells the bone-marrow is one of the most important tissues of the human body. Just as banks build their vaults in the foundations of their buildings so as to deposit their gold reserves in the safety and security of their depths, similarly the body has used the most protected places in the human body, the interior of the bones, to deposit there the coin and gold of the cell state: the blood. (The bone-marrow will be dealt with in greater detail in Chapter XII, "The Blood.")

"Reinforced Concrete"

Calcium and Gelatine. The connective-tissue cell which produces bone also forms two materials possessing opposite properties: collagen fibres and calcium. The fibres are deposited in a spiral arrangement and are embedded in a calcified ground substance [Fig. 42, (b) and (c)]. The reinforced concrete used in industry is constructed along exactly the same lines [Fig. 43]: flexible elastic iron wires (Ia) are embedded in concrete (Ic). Bone is a "reinforced concrete" with collagen fibres. As the comparison between the bone at (Ib) and the concrete wall beneath it shows, bone is much more strongly constructed. This has been proved by various tests. Bone will carry a load thirty times greater than that which brick can support, three times as great as the maximum for granite, and almost as great as the load carried by cast-iron bars. Its tensile strength surpasses even that of cast iron. In accordance with the principle of exercise, the strength of a bone increases with the magnitude of the strain to which it is subjected. The strongest of all human bones is

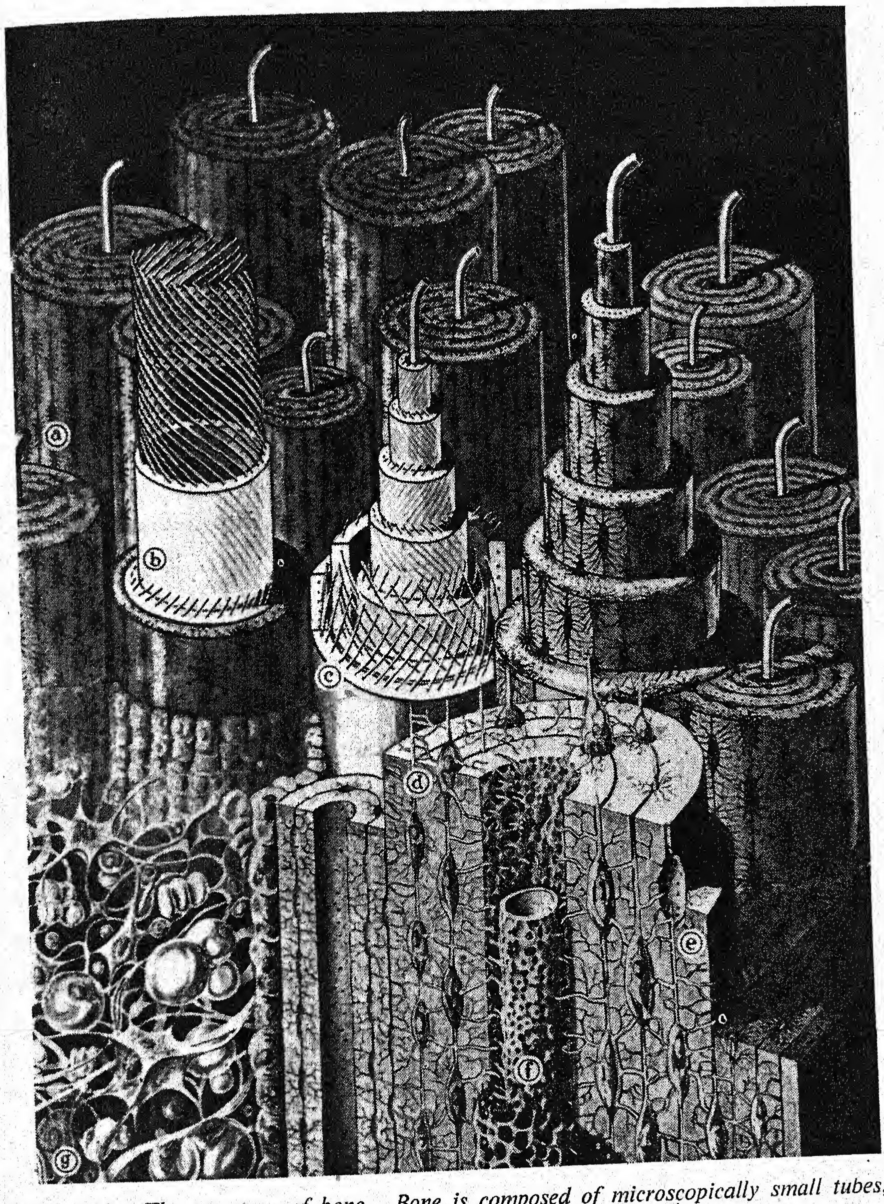


FIG. 42. *The structure of bone. Bone is composed of microscopically small tubes, within each of which passes a blood vessel and whose walls consist of concentric layers of calcium (b) and connective-tissue fibres (c). The connective-tissue fibres run in spirals that cross one another. Between the plates, like coral animals in their shells, live the cells (d) that build up the tissue in layers (e). They are connected with the blood vessels (f) by means of delicate processes. The compact bone wall surrounds the bony cavity, which is filled with soft, spongy tissue—the bone-marrow (g).*

the shin-bone, which can support a load of 3,600 pounds, approximately thirty times its normal load. Thus a shin-bone could support a platform upon which twenty people were standing.

Despite its great strength and firmness, bone is tolerably flexible owing to its high fibre content. By compressing it in a vice, the breadth of a fresh human skull can be decreased by ten per cent before it cracks. A skull can be dropped on a stone floor without breaking it. Billiard balls made of polished bone demonstrate very impressively, when they collide and rebound with great elasticity and springiness during play, the apparently contradictory union of hardness and elasticity which has been realized in the formation of bone.

The Bones in Infancy

A bone can be deprived of either its calcium or its collagen as one desires. By soaking a bone in dilute hydrochloric acid the calcium may be dissolved and removed, after which the remaining organic portion, consisting of the collagen fibres and constituting a flexible mass, can be bent and twisted like a rope (IIa). On the other hand, if a bone is calcined, the cells and the fibres are burnt (IIc), leaving a calcium framework analogous to that of a dead coral polyp. In the newborn infant many parts consist only of cartilage and contain little osseous tissue. As the child grows and develops, these structures acquire a progressively greater calcium content. During the first year of life the proportion of calcium and other mineral substances to the organic material (gelatine) is as 1:8. At the age of eighty this proportion is reversed to 8:1! We begin our life as a "jelly-fish" and end it as a "coral."

A child is able to execute almost unbelievable contortions of its body without breaking any bones. An old person, however, may fracture a rib simply as a result of an awkward movement which brings him into abrupt contact with some sharp edge or hard object. A boy plays football as if he were himself made of rubber (IIIb), while an old man toddles along cautiously as if he had glass rods instead of bones in his legs (IIIc). To be sure, they are not glass rods, but rather chalk pillars: 80 per cent calcium! they break easily, but they mend with difficulty.

Youth and Age

In old age a fractured thigh-bone may be fatal; for the old person is now confined to bed, which generally signifies the beginning of the end. Youth is rubber, age is glass: or if one wishes to express it somewhat more precisely: youth is gelatine, age is chalk.

Like every vital process, the calcification of cartilage to form bone is not a simple act, but rather a complicated and as yet not completely elucidated proceeding, for which, in addition to calcium, the child needs phosphorus, hormones, vitamins, and sunlight. If any of these structural elements are lacking, the bones do not become hard, but remain soft, bend under the load of the body, and give rise to the typical picture of rickets (IIIa).

Fractures of Bone. Despite its ideal properties as a supporting material, even healthy bone sometimes breaks as a result of violence [Fig. 44]. If a bone is simply cracked, part of the shaft being broken and the remainder bent, we speak of an

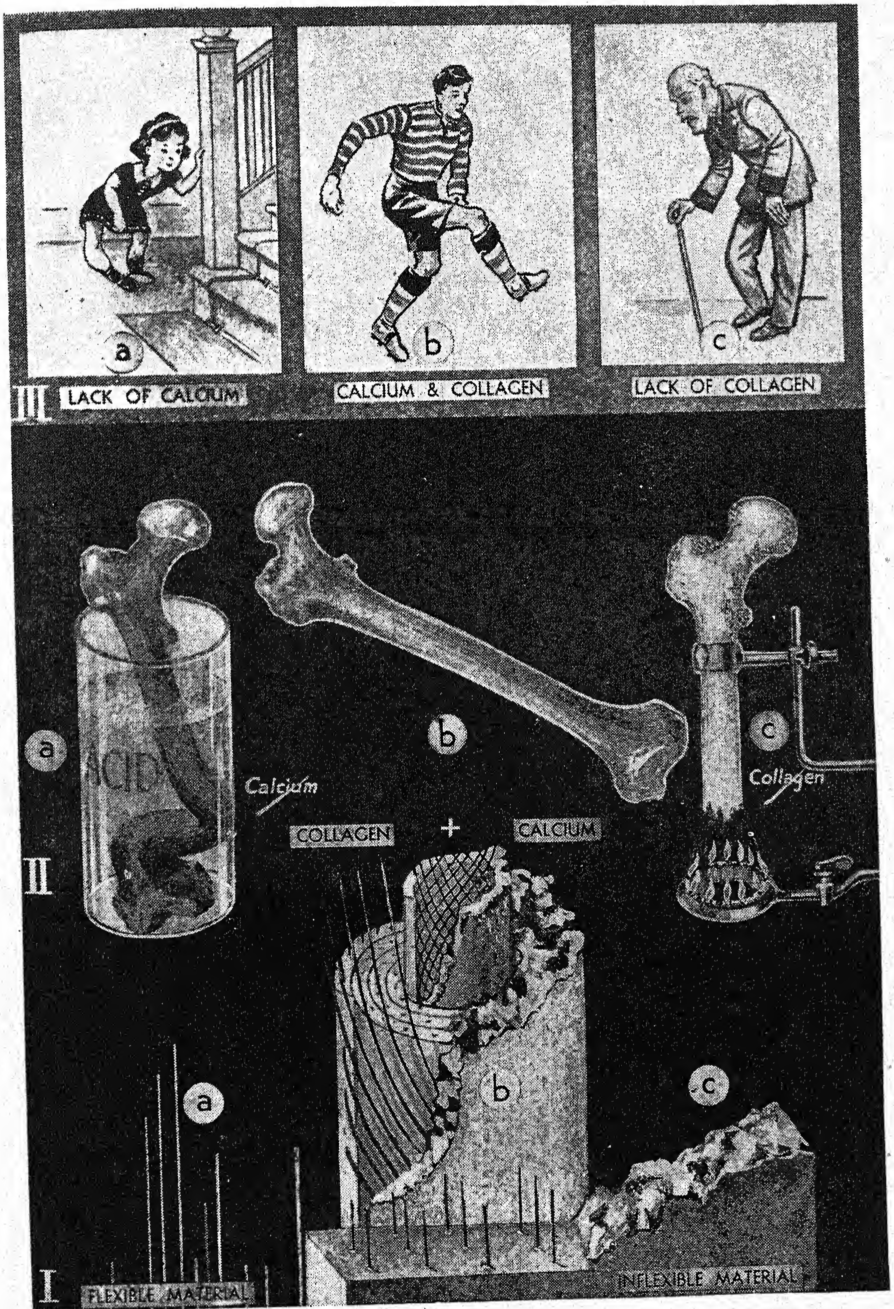


FIG. 43. *For bone to be tough as well as flexible, both calcium and collagen must be present in suitable proportions. These proportions vary with the age of the bone.*

infraction, or more usually of a greenstick fracture (a). If there is a complete break, it is called a simple fracture (b). Where a bone is broken into more than two fragments, the condition is described as a comminuted fracture (c). Where the fracture fragments pierce the muscles and the skin, establishing a tract between the fragments and the outside of the skin, as often occurs in serious accidents, a compound fracture exists (d). Owing to the severe damage to the soft tissues, the danger of infection, and the difficulty of reduction, a compound fracture is a serious injury.

Fundamentally, in treating a fractured bone, we are concerned with bringing the fragments into as close alignment as possible, just as we do when we mend a broken saucer. However, we do not have to supply any glue in the former case because the connective-tissue cells produce it themselves. Bone tissue possesses to an extraordinary degree the power of regeneration. When bone is broken there is a coincident tearing and laceration of the bone and soft tissues. Some of the injured tissue dies and is autolysed by ferments released by the death of the cells. The entire area containing the bone-ends and the surrounding soft tissue structures is bound together by clotted blood and lymph. Within a few hours after the injury young connective-tissue cells (fibroblasts) appear in this clot as the first step in the repair of the fracture.

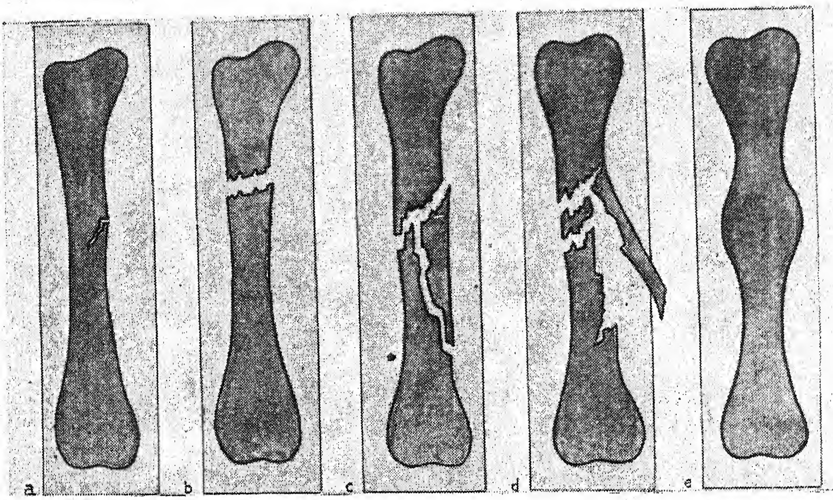


FIG. 44. *Bone fractures: (a) fissure; (b) simple fracture; (c) comminuted fracture; (d) compound fracture; (e) thick callus resulting from the healing of a fracture.*

These new cells divide and proliferate rapidly and become infiltrated with calcium. Within seventy-two to ninety-six hours this mass of cells forms a tissue uniting the ends of the bones. In general this is the process by which healing occurs in any wound. Calcium continues to be deposited in this newly formed tissue, leading to the formation of a nodular swelling, a callus, similar to that which may be observed in a broken and healing tree limb. The continued deposition of calcium leads

eventually to the formation of hard bone, which under the influence of the normal stress and strain of use over a period of months is arranged along the lines of pressure as in normal bone. This process frequently takes as long as one year before it is completed [Fig. 44 (e)].

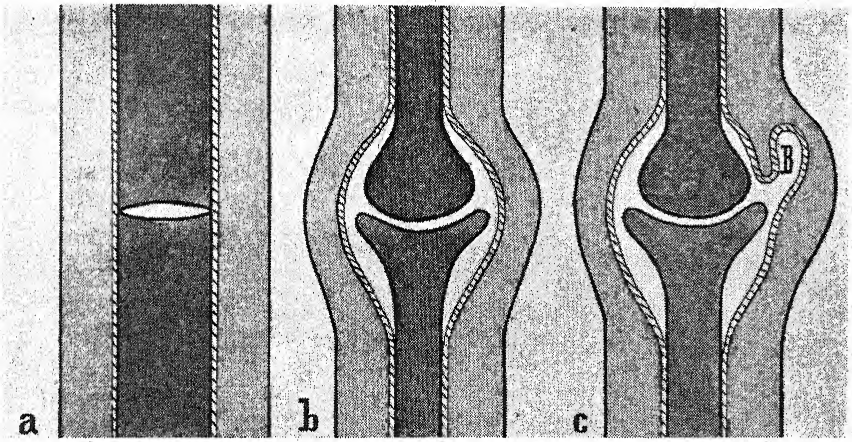


FIG. 45. *Origin of a joint: (a) formation of a joint cavity under the hermetically sealea periosteum; (b) development of the contiguous bone-ends to form articular surfaces; (c) sacculation of the joint capsule to form a mucous bursa (B). The two surfaces ot the joint which are in contact are moistened and lubricated by the so-called synovial fluid.*

After a fracture has been reduced, and the edges of the fragments have been brought into perfect alignment and checked by means of an X-ray examination, the broken limb is usually immobilized for several weeks in a plaster cast. A plaster cast is made by using plaster bandages. These are rolls of bandage material in which the meshes have been filled with plaster of paris. Shortly before being applied, plaster bandages are placed in a pail of warm water until they are thoroughly saturated. The bandage is applied to the broken limb smoothly and snugly, while at the same time the plaster is thoroughly and carefully rubbed in so that after the water evaporates, a hard homogeneous cast results which effectively limits motion. In certain types of fracture—for example, of the ankle—a walking iron, consisting essentially of a bent iron hoop, the two ends of which have a transverse bar, may be applied together with the plaster cast, so that the patient can begin to walk soon after the reduction of the fracture, or at the latest after a few days.

The Joints. Wherever two bones glide over one another, articulations permitting movement arise. They are known as joints. If a person sustains a fracture where the fragments do not unite but continue to rub against each other, a typical, even though imperfect, joint is produced. This is called a " false joint " (pseudarthrosis). Even before the embryo executes any movements, joints develop under the influence of heredity at those points where they were acquired by its ancestors. At first the arm of the fœtus is a solid rod of cartilage enclosed in an air-tight

sheath, the perichondrium [Fig. 45]. The cells in the central portion of the embryonic cartilage liquefy, so that a relatively large cavity, the joint cavity, is formed (a). The peripheral part of the connective tissue enclosing the joint cavity is transformed into a dense fibrous capsule. The two cartilages (or bones) rub against each other and develop two smooth contiguous surfaces (b). These surfaces are moistened by a small amount of glairy fluid. This synovial fluid, as it is called, probably arises from the liquefaction of the connective-tissue cells, and serves to permit smooth functioning of the joints with very little friction.

The joints are classified in groups according to the shape of the articu-

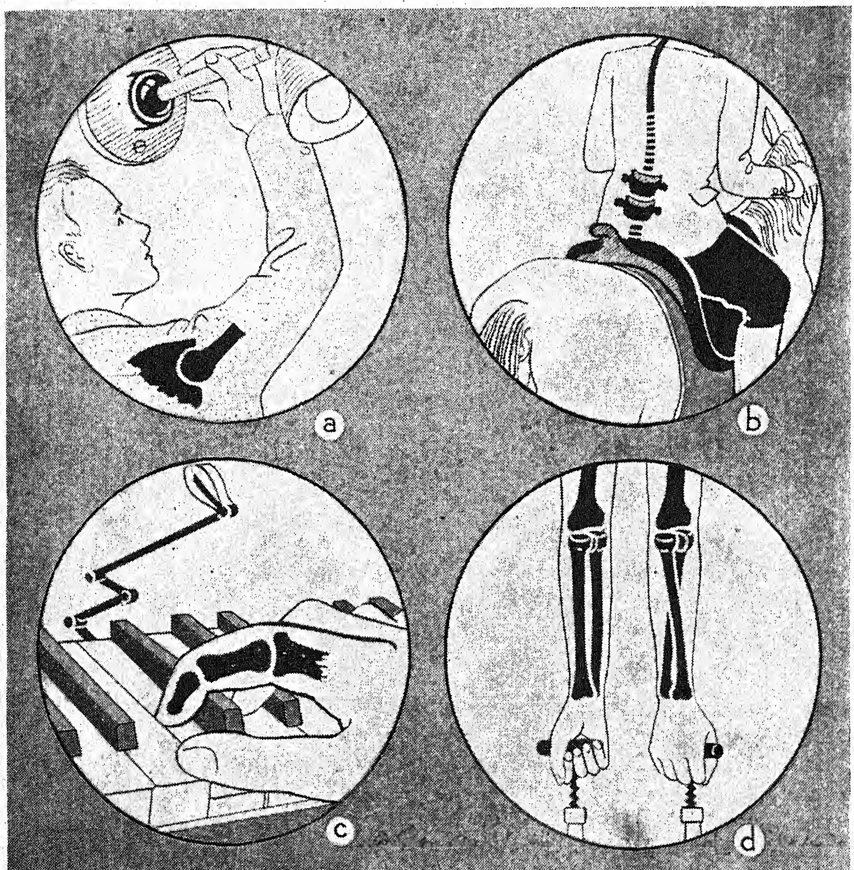


FIG. 46. *The four most important types of joints in the human skeleton. Ball-and-socket joint (a): in a joint of this pattern (shoulder) the bones can be moved in all directions; (b) saddle joint: in such a joint (vertebræ) the bones move in two directions like a rider in a saddle; (c) hinge joint: in a hinge joint (finger) the bones move in one direction like the keys of a piano or the blade of a pocket-knife; (d) rotary joint: in a rotary joint (elbow) the bones move about their longitudinal axis like a corkscrew.*

lating surfaces [Fig. 46]. In the human body the joint with the greatest range of motion is the ball-and-socket joint at the shoulder (a). A ball-and-socket joint allows of movements around an indefinite number of axes in space. The largest joint of this type in the body is the hip-joint, although it does not permit as great a range of motion as the shoulder-joint because the head of the thigh-bone (femur) is closely fitted into and embraced by the socket of the hip-joint, resulting in a limitation of its movements. In our daily surroundings we see numerous models of ball-and-socket joints in technical appliances. The arms of electric table-lamps are frequently equipped with such joints so that they can be turned in all directions.

If the joint surfaces do not develop a spherical form, but become ellipti cal, we have an ellipsoid joint, where an egg-shaped articular surface is re ceived into an elliptical cavity in such a manner as to permit of movement by the gliding of one bone over another. The wrist-joint is an example of this type of articulation. For this reason most of the movements executed by the wrist, as in fencing, are not circular, like the movements of the arm, but rather elliptical.

If an ellipsoid joint is ground down along its two chief axes in such a manner that the opposing joint surfaces become reciprocally concavo-convex, we have a saddle-shaped joint, in which the bones, like a rider in a saddle, can move in only two directions. The vertebræ of the backbone are separated by saddle-joints, so that the backbone can be bent in only two directions, backward and forward, and laterally (b).

A third type of joint is the hinge-joint. Here the articulating surfaces are shaped in such a manner that the bones can only be moved to and fro in one plane. The hinge-joint is the most common type in the body

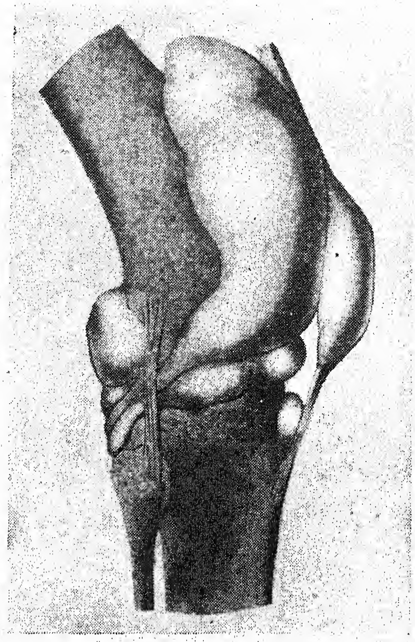


FIG. 47. *All joints, like the knee-joint shown here, are padded with numerous mucous bursæ, which act like water-cushions and protect against blows.*

and in technology. Doors, pocket-knives, and piano keys all move on hinge-joints. The fingers with which we strike the piano keys articulate with the bones of the palm of the hand by means of ball-and-socket joints, but the joints between the bones of the fingers themselves are hinge-joints (c).

Some bones rotate about their longitudinal axis like a corkscrew or an egg-beater. In doing so they move in a pivot- or rotary-joint, generally formed by a pivot-like process turning within a ring, or a ring rotating on a pivot. The pivot-joints

of the body are generally combined with hinge-joints. The two largest rotary-joints, combined with hinge-joints, are to be found at the base of the skull and in the elbow. When we nod our heads in assent, we are moving the skull on a hinge-joint. On the other hand, when we turn our heads from side to side in denial, the skull moves on a pivot-joint [Fig. 60]. When wood is sawed with a hand-saw, the elbow moves on a hinge-joint; and when we turn a corkscrew, or a key in a lock, we set the rotary-joint of the elbow in motion [Fig. 46 (d)].

Joints develop under an air-tight, enveloping perichondrium, the connective-tissue sheath of the cartilage [Fig. 45 (a)]. The ends of the bones

FIG. 48. *A sprain is the result of a distortion of the joint so that the capsule and ligaments are torn and blood or lymph escapes from the damaged vessels. The bone, however, remains in its socket.*

remain covered by cartilage so that they will not become abraded by rubbing against one another, but will glide smoothly over one another. These cartilages, as well as the other parts of the joint space, develop delicate, minute processes, resembling the nap of velvet, which secrete a whitish fluid something like raw egg-white in consistency. This is the synovial fluid, which, like oil in a machine, reduces friction between the articulating surfaces and helps the smooth functioning of the joint. The material for the production of the synovial fluid is furnished by the blood. The lining of the joint is an automatically functioning grease-box. If the joint is at rest, little synovial fluid is produced, and the joint becomes creaky.

In addition the capsule of the joint also possesses certain small sacs containing a clear viscid fluid. These structures are called mucous bursæ [Fig. 47]. The mucous bursæ pad the joint like water-cushions. In Fig. 47 the bursæ of the knee-joint may be seen very clearly after having been artificially distended. If the bursæ are chronically irritated they become thickened. Charwomen, who spend a great deal of their time on their knees, often develop a swelling of the corresponding bursæ (housemaid's knee). A similar condition occurs as an occupational disease among miners. While working in narrow seams, the miner often supports himself on his elbow, which he uses as a fulcrum in delivering a blow with his pick. This pressure produces an inflammation and swelling of the bursa at the elbow, a condition known as "miner's beat elbow."

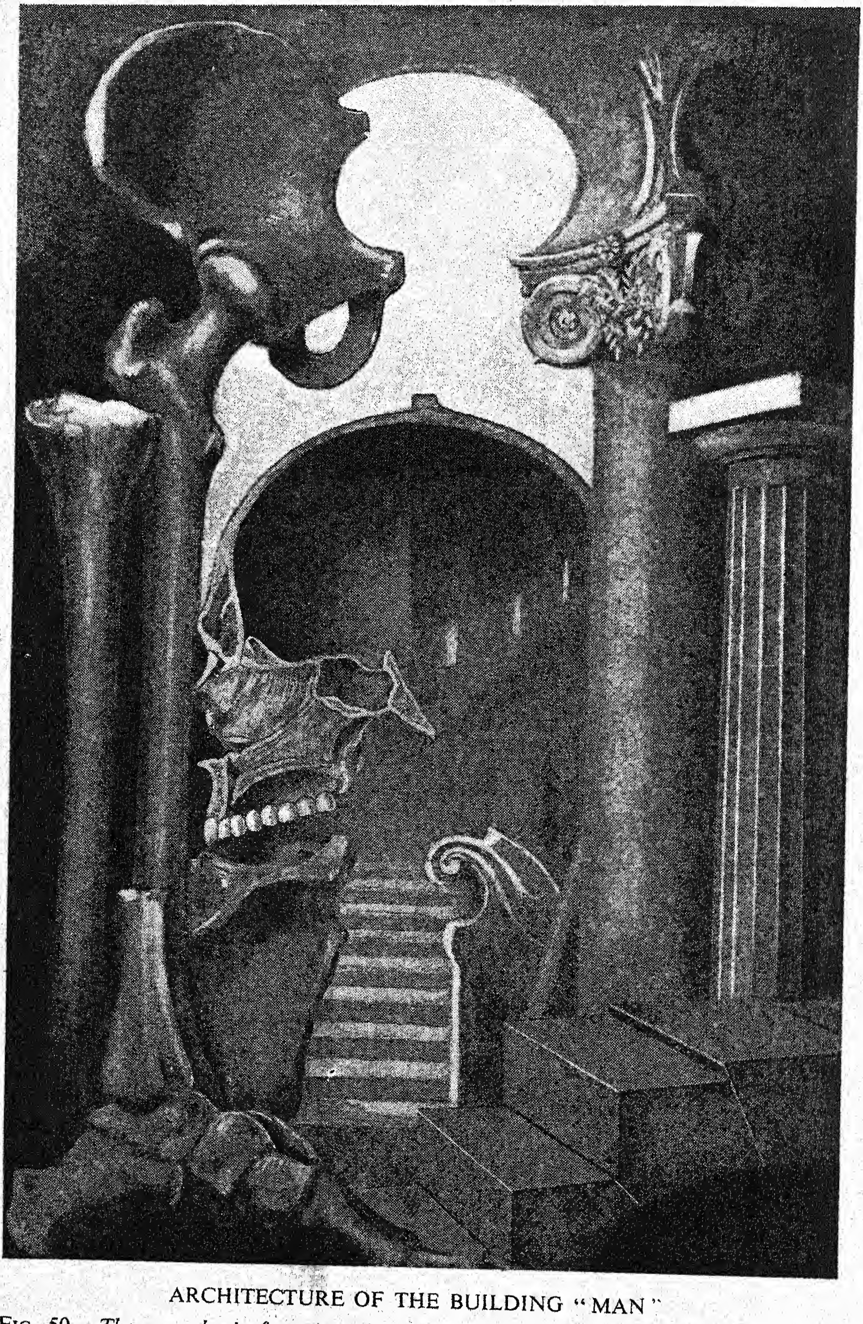
Sprains. If a joint is stretched to such a degree that a ligament or the

joint capsule tears at some point, we speak of a sprain [Fig. 48]. This condition is almost always accompanied by some internal bleeding at the point of injury. The sprained joint is painful, swells in consequence of the bleeding so that the skin feels doughy, and the injured person becomes unable to move the joint for several days. This immobilization is a protective measure taken by the body to prevent any further use of the joint until it has healed. If there is an extensive effusion of blood under the skin, the latter becomes discoloured, first turning red, then taking on a greenish and bluish hue. A sprain is generally a harmless occurrence. The joint is put at rest by bandaging it so that any movement is impossible. After several days of rest, baths and massage assist in clearing up the condition by hastening the absorption of the effused blood and other fluids collected at the point of injury. After a short period of rest a sprained joint is once more fit for use.

Dislocations. A very different condition arises when the ligaments, on being put under tension, are not only stretched excessively, but are actually torn to such a degree that the bone escapes from the joint and becomes impacted among the neighbouring ligaments and muscles. This condition is described as a dislocation of the joint [Fig. 49]. This type of injury is much more serious than a simple sprain. Under favourable conditions the bone may immediately be replaced in its socket and the dislocation reduced. If someone with training is present at the scene of the accident, the dislocation may be reduced immediately. Generally, however, the muscles contract rigidly and keep the dislocated bone in its false position so firmly that the victim

FIG. 49. *In a dislocation the ligaments are torn to such a degree that the ends of the bones leave the joint and remain separated, the capsule being torn or stretched.*

writhes in pain as soon as even the slightest attempt is made to touch the dislocated limb. In such a case it is best not to undertake anything, but to leave the reduction of the dislocation to a physician, who is acquainted with the anatomy of the parts and knows best how to return the bone to its joint. It generally takes several weeks before the torn ligaments and joint capsule heal and the joint is once again fit for regular, normal use.



ARCHITECTURE OF THE BUILDING "MAN"

FIG. 50. *The same basic forms are found in the human skeleton as are employed in architecture—forms whose function it is to provide support and strength. (Page 68).*

CHAPTER V

The Theory of Body Proportions

THE ERECT POSTURE. THE BODY—A THREE-STOREY TOWER. THE PROPORTIONS OF ADULT AND CHILD. REGULATION OF BODY PROPORTIONS BY THE ENDOCRINE GLANDS. THE SIZE OF THE BODY. HOW MAN'S FRAME IS ENLARGING. THE FORMS OF THE BONES.

If one wishes to state concisely wherein man differs fundamentally from all other creatures, his erect posture must undoubtedly be regarded as pre-eminently characteristic. An animal stands on four limbs and employs them all for locomotion. It has no free hand and must therefore employ its head and teeth as tools and weapons. Even birds, which like man have assumed an erect position and become bipeds, have not made the most of this transformation, since they too use their anterior limbs for flying and must therefore perform all necessary manipulations with their heads.

Jaw or Brain?

As a result their jaws have stayed large and have undergone a specialized form of development to a much greater degree than among other land animals. They have become the hard, horny beaks with which we are familiar. The apes are closer to man in this respect, but even in them the hand is not yet entirely free. They use their arms chiefly as organs for climbing and locomotion, so that among these animals too the jaw is still excessively large, while the cranial cavity is small. In all animals, including the apes, the head is a supporting structure for the teeth-bearing jaw. The centre of gravity of the animal skull does not lie in the region of the brain, but in that of the jaw.

Freedom of the Arms

A pre-eminent characteristic of man is the complete liberation of the anterior limbs from their locomotor function. Man is the only creature that does not use his arms for locomotion but rather for independent actions. Most other creatures perform their work with their jaws; they dig, bore, burrow, and grasp their food with their mouths. In man the arms have taken over from the jaws the function of performing all tasks outside the body. The jaws have become a part of the digestive apparatus, like the pharynx, stomach, and intestine. As a result they have grown smaller, and the cranial cavity with its contents, the brain, has expanded enormously. Liberation of the arms from the function of locomotion, transfer of the former duties of the jaws to the hands, decrease in the size of the jaws, and expansion of the brain—these have marked the path of human development and are

characteristic features of mankind.

As a result of the erection of the body the neck acquired a greater degree of freedom, leading to the development within it of the vocal apparatus. Among birds, too, a singing voice has developed as a consequence of erect posture.

Development of Speech

In the case of man, however, the decrease in the size of the jaws has been accompanied by a concomitant development of the brain and the vocal apparatus. From the co-operation of these two structures there has arisen, in addition to the wider range of action of the hand and the thought accomplishments of the brain, a third achievement, speech. Thought, the use of the hands, and speech have developed concomitantly with the erection of the body.

Yet the erect posture has brought not only advantages for man, but disadvantages as well. As a result of raising the head, the olfactory sense has become weaker, and the specifically human nasal maladies (narrowing of the nasal chambers, deviations of the nasal septum, chronic catarrh) have appeared. In consequence of the erect posture, the internal dynamics of the body have been altered.

Man's Unnatural Posture

Man has become a biped, but his body is built essentially like that of a quadruped, so that in relation to his internal organization his present posture is as unnatural as if an automobile should suddenly raise its front wheels in the air and begin to roll along on its back wheels. All the organs of the human body, the lungs, heart, blood vessels, and digestive apparatus, were originally adjusted to a horizontal posture of the body and have suffered as a result of the transfer to an erect position. The aeration of the lungs has been impeded to some extent, and the apices of the lungs expand very little during normal respiration. Similarly, the conditions for the circulation of the blood have likewise grown worse. In the animal body the heart needs only to drive the blood through a system of horizontal tubes; in the human body the blood must be pumped up from the depths. The heart and blood vessels of man have a greater burden, and this may be a reason why they tend to degenerate relatively early. The blood stagnates easily in the deeply situated parts of the body. The veins swell, becoming varicose veins in the legs, and hæmorrhoids in the rectum.

Awkward Suspension

In the horizontal animal body the internal organs are suspended from the backbone like the washing on a line; in the erect human body they hang like a flag on a flag-pole. The backbone must sustain the pull exerted by the combined burden of the viscera, so that individuals with a normally curved spinal column may almost be regarded as exceptions. In some cases the ligaments from which the viscera are suspended relax in the course of years and the organs sink down (ptosis of the stomach, floating kidney, prolapse of the uterus, etc.). Through spaces in the overtaxed abdominal wall the intestines may descend and enter the scrotum, producing an inguinal hernia or rupture.

The Body—a Three-Storey Tower. From an architectonic point of view the body is a walking tower, which instead of standing on firm foundations moves on pillars represented by

the legs [Fig. 51]. On this moving foundation are three storeys. The uppermost one is the skull; in it live organs of the outer germ layer, the brain and many of the sense organs (I). The middle one is the chest; here lives the central organ of the middle germ layer, the heart, together with the middle portion of the skeleton (II). The lower storey is the abdomen; in it resides the organ system of the inner germ layer, the digestive apparatus (III).

The Proportions of the Adult. Peculiar size relationships, called proportions, exist between the parts of the tower [Fig. 52]. If an individual extends his arms, their span corresponds to the height of the body. As the ancient Egyptians had already discovered, the height of the body is nineteen times the length of the middle finger. The trunk is three times the height of the head, an arm is three times as long as a hand, and a leg three times as long as a foot. The surprising proportional relationships between the height of the head and that of the body are shown in (a). It should be noted, however, that these relationships are only approximate.

Remarkable Measurements

The relations between the measurements of the body and the spinal column are quite remarkable (b). The end of the spinal column lies exactly in the centre of the body. If one quarter the length of the vertebral column be added to the upper cervical end of the backbone, we reach the crown of the head. If the length of a backbone plus the extra quarter be added to the vertebral column, it extends to the ground. By means of this division the height of the body may be divided into decimal portions. As shown in the illustration, the location of important points of the body, such as the nasal orifices, the upper and lower edges of the breastbone, the navel, and the

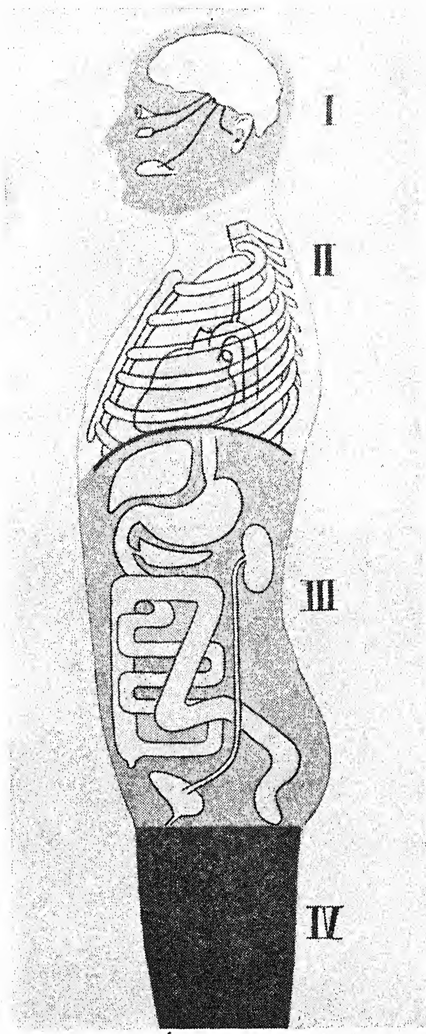


FIG. 51. *The human body is a three-storey tower. On the foundation of the thighs (IV) stand the three storeys—abdomen (III), chest (II), head (I). These three storeys correspond to the inner, the outer, and the middle germ layer respectively.*

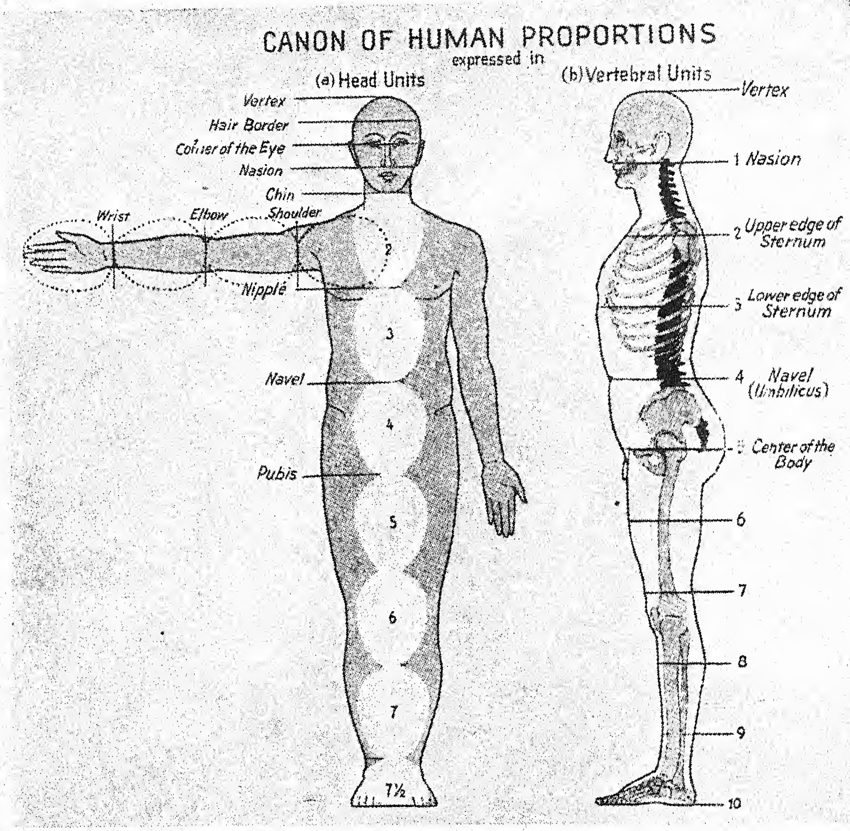


FIG. 52. *The proportions of the human body. In the size relationships of its various parts the human body exhibits very remarkable proportions, which are known collectively as the canon. At (a) it is seen that the whole body is seven and a half times as long as the head; (b) shows the body divided into ten equal portions, of which the head and the spinal column together comprise five—half the height of the body.*

pubic symphisis, coincides with these decimals.

The proportions of the face are also very striking [Fig. 53]. A line drawn from crown to chin may be divided into five equal parts. The eyes are separated from each other by approximately the width of an eye. This distance is likewise equivalent to the width of the mouth and the widest part of the nose.

The proportions of the human body prove to us that profound internal laws of harmony regulate the formation of the body. They also reveal to us the mystery of human beauty. We regard as beautiful those individuals in whom these proportions are embodied as purely as possible, for instance in the classically beautiful statue in Fig. 54.

The Proportions of the Child. The laws of proportion discussed above are valid only for the adult human body. A child has proportions very different from those of an adult. A

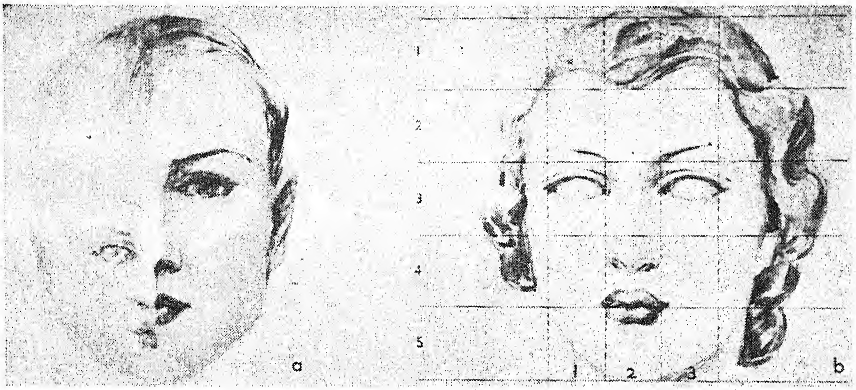


FIG. 53. *The proportions of the human head. (a) A child's head has different proportions from those of an adult. Not only does the head grow, but in the process of growth the various parts of the head shift their position relatively to one another. (b) The proportions of the features in an adult. It is plain that the lower part of the skull grows much more rapidly during the early part of life than does the upper part.*

child is not only a smaller, but also a differently constructed human being [Fig. 53]. A child differs from an adult in the relatively large size of the head and the shortness of its legs. In the course of the period of growth the child's head is only doubled in size, while the trunk is tripled, the arms grow four times and the legs five times as long [Fig. 55]. If the head of an adult were to be replaced with one relatively as large as the head he bore in childhood, it would be so large that it would extend from the top of the head to the level of his nipples.

The Endocrine Glands. Like all metabolic processes, growth and the changes of proportion connected with it are controlled by the system of endocrine glands. The endocrine glands that are most important for growth are the thyroid in the neck, the hypophysis (also called the pituitary), in the brain, the thymus, located in the chest, and the sex gland. The pituitary stimulates the growth of the bones in the region of the cartilage-bone border, thus controlling those processes that have been represented in Figure 39 as a battle between armies of cells. If pituitary secretion is excessive, the arms and legs grow too long and the hands and feet become disproportionately large. If the quantity of secretion is too small, the limbs remain short. When he was ten years old, Thomas Hasler, the son of a Bavarian peasant, received a blow on the head. From this time on he began to grow abnormally. After two years he was over four feet tall. At the age of twenty-four he had attained a height of over seven feet, and at twenty-five—he was dead, because his entire condition had been pathological. Most giants are people with pituitary disease. Such "pituitary giants" are like the giant Machnow, photographed with the anthropologist Luschan [Fig. 56]. As is evident from the picture, Machnow has a normal head and a moderately developed thorax on legs of elephantine proportions, while his hands are

FIG. 54. *The classical (Greek) ideal of female beauty. It is interesting to compare these body proportions with those of the Hottentot ideal shown in Fig. 36.*

enormously enlarged. Injury or disease of the pituitary may, on the other hand, lead to cessation of its function and consequently an arrest of growth. A child suffered a head injury and stopped growing. At the age of twenty-four it was little more than three feet tall. It was, as we say, a hypophyseal or pituitary dwarf.

The second growth gland of the body appears to be the thymus. The child is born with a large thymus, which continues to grow throughout childhood and begins to atrophy at the onset of puberty. The thymus seems to exist in a reciprocal functional relationship to the sex gland. As long as an individual has a functioning thymus, the sex gland is small. This may explain in part perhaps why man gradually ceases to grow after achieving sexual maturity. The influence of the sex gland apparently overwhelms that of the thymus, thus slowing down and finally stopping the process of growth. A normal individual continues to grow until the appearance of puberty, and then gradually stops growing in the same degree to which he becomes sexually mature. When he has attained full sexual maturity, at about the age of twenty-two, growth ceases.

If the sex gland develops too soon and "brakes" the growth gland (thymus) too early, the individual does not grow sufficiently and remains below the average in height. Above all, the legs remain short, because they grow later and must grow more than other parts of the body in order for the child to attain the normal proportions of the adult. Prematurely developed individuals remain thickset. They carry a large, striking head on a body which is too small. This type is not infrequently found among intellectual people. Napoleon, who was already conquering the world at the head of his armies at an age when the majority of men have achieved little, and who attained the height of his power at the age of forty, is the type of a thickset individual. Goethe, Beethoven, Richard Wagner, Edison, and many other highly creative people represent this type.

On the other hand, if the sex gland develops too late, the thymus continues to function and the individual grows to more than the average

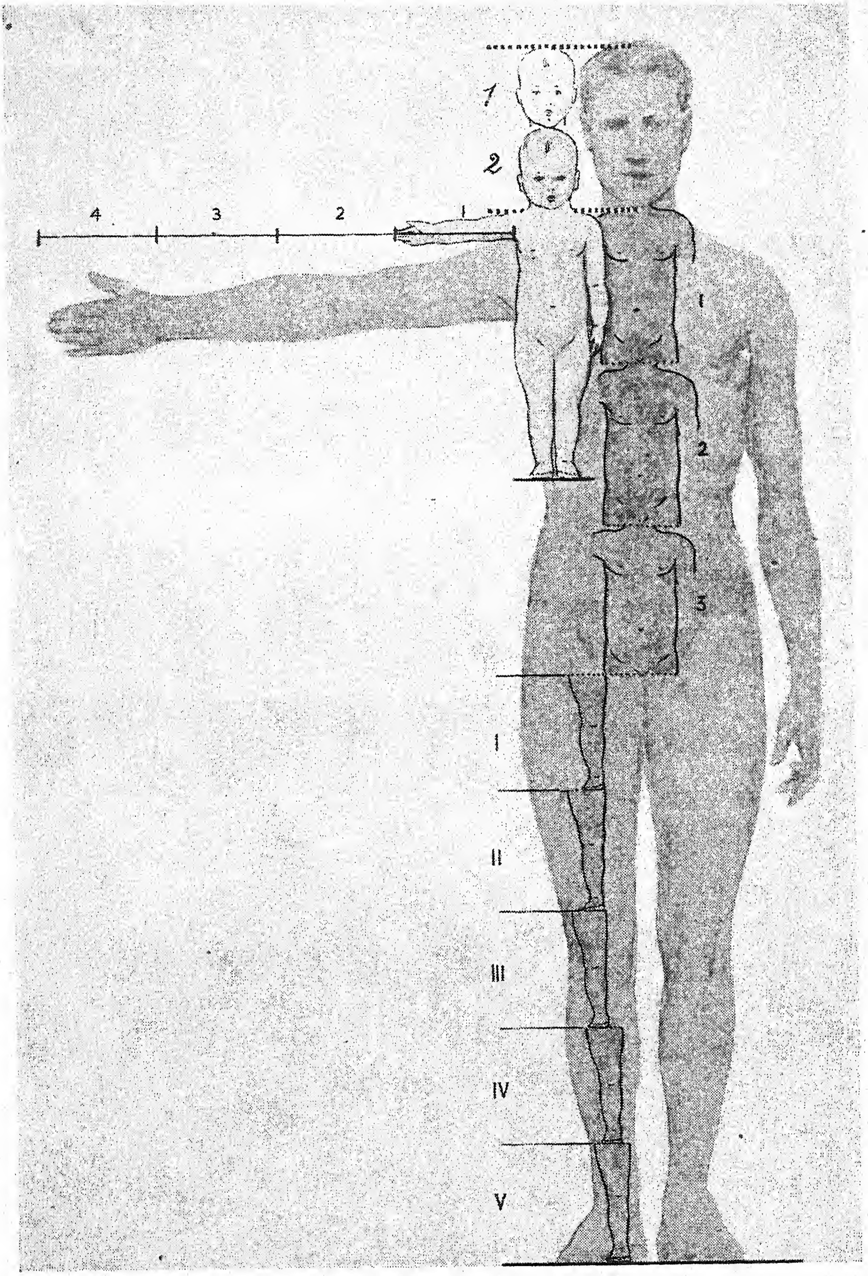


FIG. 55. *A child's body is not simply a miniature of that of an adult, but is proportioned quite differently. During growth to maturity, the size of the head is doubled, that of the trunk is trebled, the arm becomes four times, and the leg five times, as long.*

height. At the period when normal persons cease growing, this type of individual continues to grow, and surpasses the normal, average height for his age, attaining a height of six or six and a half feet. Individuals of this group are generally very tall and exhibit an under-development of the sexual characteristics. Men of this type are generally not very manly, speak in a high-pitched voice, and have a delicate, feminine constitution. Women of this type, owing to the weakness of their sex glands, are generally not very feminine, but are rather thin, bony, and devoid of feminine grace and softness in their movements and expressions of character.

Correcting Abnormality

Perfectly normal types are rare. Most people deviate to a greater or lesser degree from the norm. An adult can do very little about his constitution. However, attentive parents, if they have been trained to observe their children objectively, are in a position to influence decisively their children's constitutions between the ages of nine and sixteen. A child whose proportions deviate markedly from the normal can be treated by the administration of hormone preparations intended to regulate its development. By means of hikes, sun-baths, radiation treatments, a diet adjusted to the needs of the body, and encouragement to participate in athletic and gymnastic activities under the supervision of an experienced doctor, a great deal can be done to adjust any constitutional deviations.

The Size of the Body. A newborn infant is one foot eight inches long on the average and just about reaches to the knee of an adult. In the course of twenty years man triples the length of his body at birth and achieves an average height of five feet eight inches. Man continues to grow even after the age of twenty-five, attaining his maximum height at about the age of thirty-five or forty. Thereafter he shrinks by one centimetre (0.4 inch) in each decade. This shrinkage results pre-eminently from a drying-up of the cartilages in the joints and the spinal column, where the individual vertebræ are separated by cartilaginous intervertebral disks, which like railway buffers absorb shocks that occur during walking or running. On arising after a long stay in bed, one has "grown" because the intervertebral cartilages have become turgid. For a short while such an individual resembles a sofa in which new springs have been installed and the seat in consequence has been raised. As soon as this person begins to walk again, the cartilages are pressed together, become flattened, and he returns to his normal height. Every morning we are taller than we were the previous evening, but in the course of the day we again shrink.

Seasonal Growth

Growth varies with the seasons. During the summer children grow more rapidly than in the winter. Children of school age grow 0.4 centimetre during the winter months, 0.6 centimetre in the spring, and 1.0 centimetre during the summer. The male inhabitants of the temperate zones attain an average height of 170 centimetres (five feet eight inches), while the height of females is 160 centimetres (five feet four inches). An individual of average proportions weighs approximately as many kilograms as the number of centimetres

by which his height exceeds one metre. Thus a man 1.7 metres tall weighs about 70 kilograms (154 pounds); a woman whose height is 1.6 metres weighs 60 kilograms (132 pounds).

How Man's Frame is Enlarging. We frequently read of the progressive degeneration of mankind throughout history. This theory of progressive degeneration has been prevalent for millennia, yet men have continued to go about their business without any apparent concern. Hesiod, one of the oldest Greek writers, who lived at the commencement of the most flourishing centuries in the history of Greece, already complains of the deterioration of the younger generation and laments the passing of the "good old times." Present-day man is not degenerating, but is improving! The better animals and human beings are fed, the larger they become. Shetland ponies are descended from the same race as the strong horses of Brittany. They have become small, however, because they live on the bare Highlands of Scotland, where living conditions are hard. Bushmen and Hottentots belong to one race, but the former are small because they live in the Kalahari Desert.

FIG. 56. *The giant Machnow visiting Felix von Luschan, the celebrated Austrian anthropologist and ethnographer. Machnow is a typical hypophyseal giant. The relatively normal trunk is supported on enormously elongated legs. Observe, too, his thickened and elephantine hands.*

Effect of Nutrition

Moreover, among civilized peoples body size increases with wealth and well-being. London workers are smaller than leisured country-dwellers, but the former are taller than their grandfathers, because human nutrition has grown progressively better from decade to decade. Since the Stone Age the average size of man has increased by five centimetres (nearly two inches). During the past century alone the average stature in Sweden has increased by 0.7 centimetres, by 1.2 centimetres in Germany, and in Savoy under French rule by several centimetres. When members of the Scottish nobility wanted to present a pageant for Queen Victoria during her wedding tour, they found that the historic suits of armour were too small. The descendants had outgrown the armour of their illustrious ancestors.

Environment exerts a considerable — indeed, perhaps the strongest — influence on body size. Under environment we comprehend the sum of various factors such as climate, character of the soil, water, mode of living, and so on. Peoples, families, and individuals experience changes in body size when they change their abode and with it their mode of life.

Supply and Demand

The Forms of the Bones. According to the principle of exercise, tissues increase in strength at those points where they are subjected to repeated stimuli. Wherever connective tissue in the body of a moving creature was subjected to the pull and pressure of external forces, it became stronger and was organized as bone. Thus within living beings we always find bones just where they are required, and always in forms most suitable for the corresponding organ. In constructing anything man acts according to the same principles. He uses stones as he needs them for his buildings. For foundations he takes broad, heavy blocks. For supports he raises columns, and arranges the struts in cupolas along the lines of pressure and traction, in a manner similar to the arrangement of the supporting bony lattice work within the bones of the organism. The correspondence of the architectural principles explains the coincident occurrence in the skeleton of forms and combinations of bones that remind one strikingly of human architectural creations [Fig. 50]. If the skeleton is considered from the feet upwards, all architectural "styles" will be found on it. The feet are reminiscent of the Pyramids; they are built of blocks, have a broad base, and end in an apex above. However, they do not rest flat on the ground, but are arched like the cellars of our houses, for upon them rests the entire weight of the upward-rising bone tower. Above the feet rise the columns of the legs. The form of the foreleg, with its edged shinbone, is archaic like a Doric column. The thigh is lighter, more graceful, and ends in a volute like an Ionic column. The thigh-bones bear the pelvis, which is constructed like the arch of a gate, and its union of mass and soaring lightness reminds one of a baroque portal.

Living Architecture

Yet again, the thorax above the pelvis is composed of pointed arcs, the ribs, all striving upwards in the Gothic manner; while high above all these structures the roof of the skull arches like the cupola of a Renaissance cathedral. An imaginative artist could put together a skeleton based on various elements in the history of art, by depicting it as a composition of pyramids, Doric columns, Corinthian capitals, Gothic buttresses, and Romanesque motifs. The richness of style of the human skeleton reveals its origin. It was not constructed all at once, but has become what it is today by passing through and experiencing all the ages and stages of the development of life on the earth. It is the collective product of a history of bone structure extending over millions of years of progressive evolution.

CHAPTER VI

The Skeleton

STRUCTURE OF THE SKELETON. THE VERTEBRAL COLUMN. CURVATURE OF THE SPINE. THE THORAX, RIBS, AND PELVIS. THE LIMBS. THE HAND AND FOOT. STRUCTURE OF THE SKULL. THE SKULL SPACES. THE CEPHALIC INDEX. THE CRANIAL SUTURES. THE BASE OF THE SKULL. THE HUMAN FACE. INTERMAXILLARY BONE AND HARELIP. THE LOWER JAW (MANDIBLE). MAN—THE SPEAKER.

MAN is not a machine artificially put together by combining various pieces, like an automobile, which has a precisely determinable number of parts, but rather a living creature in the midst of a process of development. At one point parts are coming into being; elsewhere others are in the process of degenerating; here historic old bones that are no longer needed coalesce, and one is at a loss as to whether they should be counted as a unit or as separate parts; at still another point bones are in a state of dissolution. In short, the number of bones varies with different individuals. The total number of bones in the adult body is more than two hundred. We may perhaps take the number 222 as an average.

The Vertebral Column. The axis of the skeleton is formed by the vertebral column composed of 33 or 34 vertebræ. The upper vertebræ are light, because they do not have much to carry, and resemble the upper storeys of high buildings; while the lower ones are strong and stout, because they function as supports, analogous to the large stone blocks in the foundations of our houses. The vertebræ are divided into five groups: cervical, thoracic, lumbar, sacral, and coccygeal. There are seven cervical vertebræ, twelve thoracic vertebræ combined with the twelve pairs of ribs, five lumbar vertebræ in the posterior wall of the abdomen; five pelvic vertebræ that have grown together to form the sacrum, and finally five coccygeal vertebræ no larger than cherries and peas

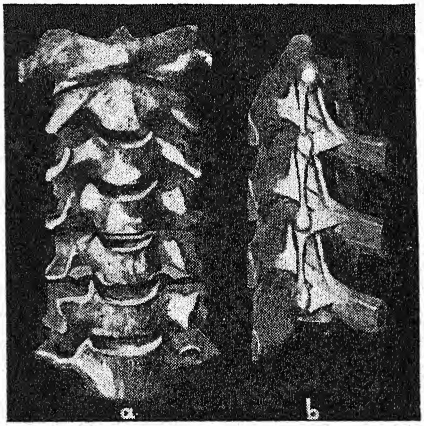


FIG. 57. *The vertebral column: (a) the vertebræ form a chain of articulated links. The uppermost vertebra is the atlas, which supports the skull. Below the atlas is the axis, which enables the head to turn from side to side. (b) Ligaments keep the vertebræ in place, yet allow movement*

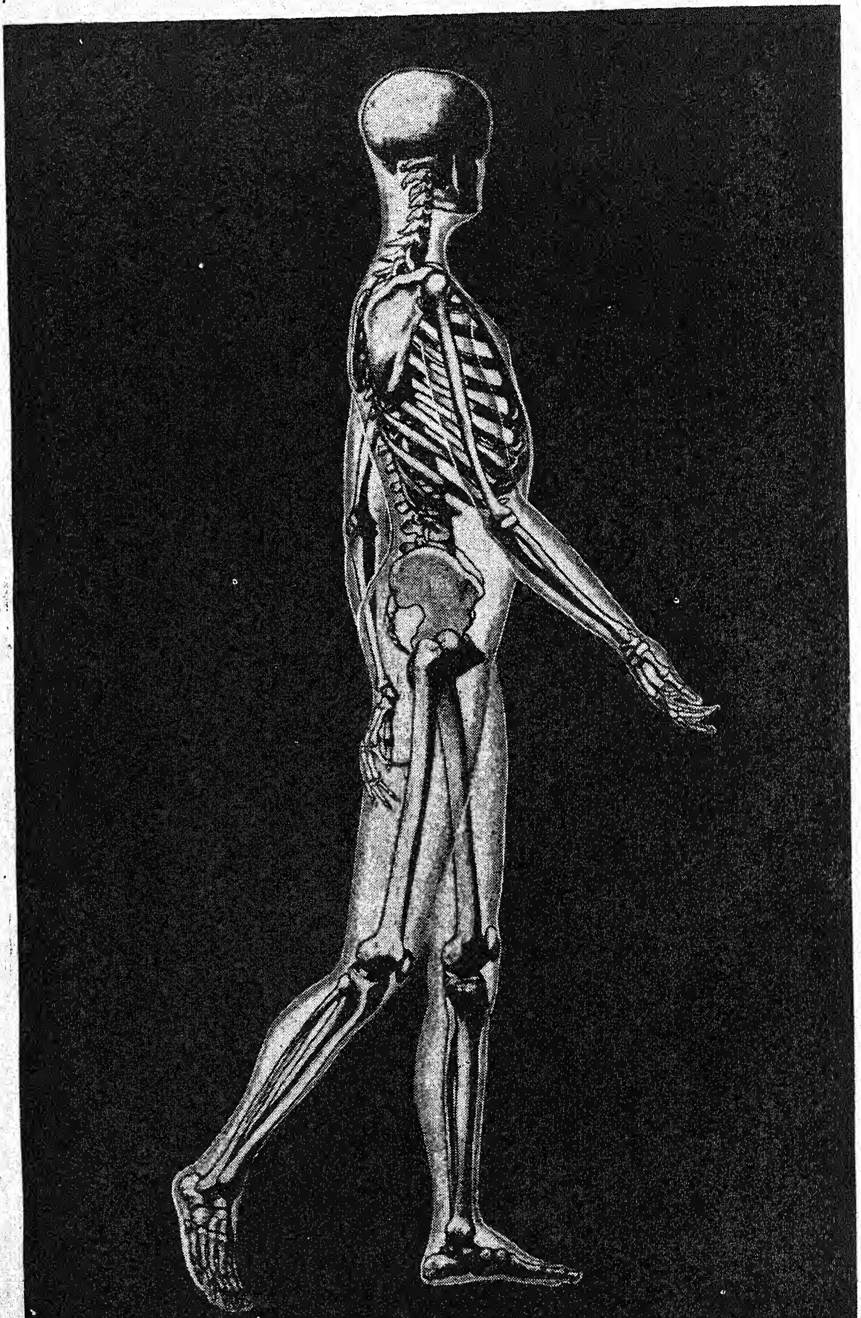


FIG. 58. *The human skeleton—masterpiece of strength and harmony.*

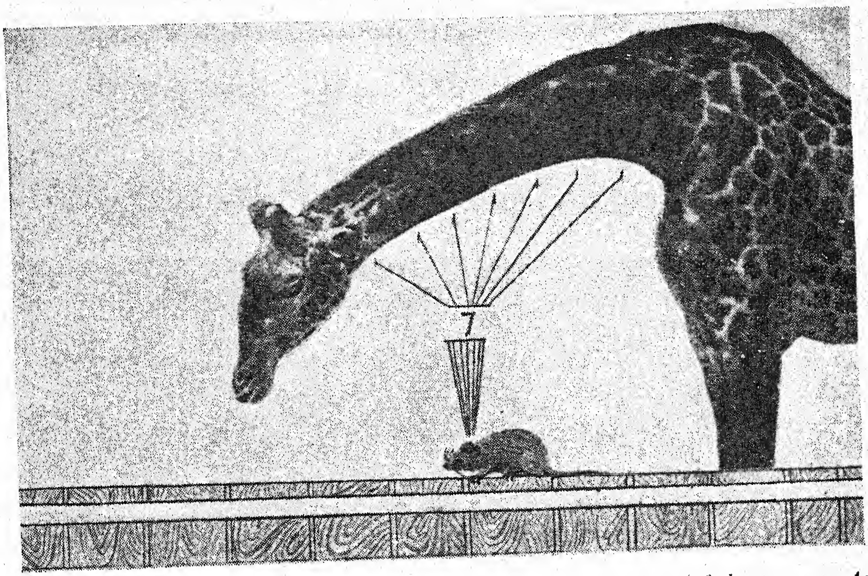


FIG. 59. *The neck of the giraffe has no more vertebræ than that of the mouse. As descendants of a common primordial form all mammals have seven cervical vertebræ.*

attached to the pelvis as degenerated remnants [Figs. 58, 62]. If we were to compare a giraffe with a tiny shrew-mouse that can walk on one's finger, or an elephant with a hedgehog, so small that the elephant's foot can crush it to a pulp, we might at first glance be willing to swear that the giraffe has at least three dozen cervical vertebræ, while the hedgehog or the shrew-mouse has only two or three. If 1,000 people were questioned regarding this matter, 996 of them would certainly give an incorrect answer. Actually, all mammals (with two remote exceptions) have seven cervical vertebræ. Apparently the primordial batrachians from which mammals are probably descended had seven cervical vertebræ, and this number has been inherited by their widely distributed descendants [Fig. 59].

The vertebræ are not simple blocks, but are shaped like signet rings and superimposed on one another, forming a hollow column within which the spinal cord is enclosed and suspended [Fig. 57]. The rings are peculiarly moulded, and at the points where their edges come into contact with one another joints have developed. Some vertebræ have no less than ten articular surfaces. Each joint permits only a very slight movement, but the sum of all the movements of the 150 vertebral joints results in the astounding fact that the spinal column as a whole can be bent like a steel ruler The first two vertebræ differ from the rest because they have become specialized to carry the head. In Figure 57 they are seen as the two uppermost vertebræ. The first is called the atlas because it bears the skull as the giant Atlas carried the earth. The second is called the axis because it has a bony peg around which the atlas carrying the skull

rotates like a railway engine on a revolving platform [Fig. 60]. Axis and atlas form a complex combined joint. When we nod the head in assent, we are see-sawing the skull on the runners of the atlas joint like a rocking-chair or a tip-cart (2). On the other hand, if the head is rotated from side to side in denial, it is being turned on the pivot-joint between the atlas and the axis as on a rotating platform (3).

Shape of the Spine

The spinal column is not a column, but rather a spiral spring bent into the shape of an S [Fig. 61]. A new-born child comes into the world with a straight backbone. Only as a result of creeping, walking, and keeping the head erect is the originally straight column bent into an S.

The S-curvature of the spinal column is an " elegant " solution of the problem in question, by means of which six advantages are gained:

1. An individual with a straight spinal column would be pulled forward by the weight of the viscera suspended anteriorly. To retain his balance he would have to pull his shoulders backward. By means of the S-curvature, however, the hanging weight of the visceral mass is kept above the lower supporting point in the pelvis, so that the individual is able to balance himself and his poorly distributed load with a tolerable degree of security while walking or standing.

2. The S-curvature absorbs all the jars of walking on a hard pavement—and they are rather hard for a biped of a hundred and fifty pounds. A straight backbone would conduct every shock from the pelvis directly to the head. Each evening we should go to bed with a terrific headache, and an awkward jump could possibly result in a skull fracture produced by means of a concussion effect.

3. The double bend of the spinal cord produces additional space; the thoracic viscera lie in the upper curvature, the abdominal organs in the lower one.

4. Owing to the repeated curvature the weight of the three masses supported by the spinal column is divided among the three arcs of the S. The upper sector carries the head, the middle one the thoracic viscera, and the lower one the abdominal organs. In a straight backbone the weight would increase from the top downwards, resulting in an unbearable load at the bottom.

5. Curvature increases the carrying capacity of the spinal column. Three superimposed arches can carry considerably more than a single column.

6. By means of its curvatures the vertebral column is protected against fracture. A tall pole breaks easily, while a doubly bent spring yields when subjected to force. How fortunate that the spinal column is not what its name indicates it to be—a column!

The Spinal Cord

If an engineer were given the job of constructing the vertebral column—a flexible column consisting of 33 rings with 150 joints and almost 1,000 ligamentary connections, capable of supporting a load of 500 pounds, and yet flexible and elastic—he would perhaps solve the problem tolerably well after a number of years of constructive activity. Yet he would not be able to equal or surpass the work of Nature. If on the day when he delivered his work, the further task were suggested to him

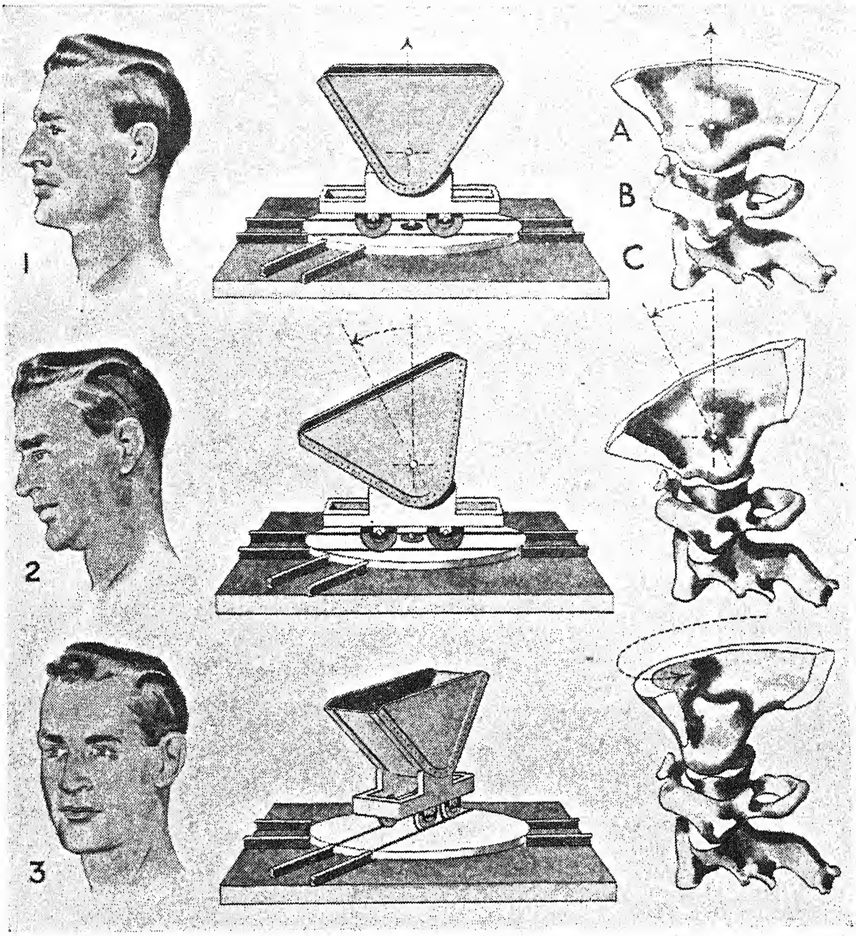


FIG. 60. *(1) The skull is situated on the vertebral column like a tip-cart on a turntable; (2) when the head nods " Yes," the cart tilts on the " runners " of the first vertebra, the " atlas "; (3) when the head says " No," the skull turns from side to side on the turntable of the second vertebra, the " axis."*

of installing the spinal cord within this vertebral column—that is, of laying a nerve cord consisting of millions of wires that pass out between the rings and are not injured in the least by any movements of the spinal column itself or the body as a whole—the engineer would certainly consider the suggestion the plan of a madman. Nature, however, has dared this difficult task and, as our well-being indicates, has solved the problem perfectly. Within the vertebral column upon which the head is balanced above, from which the viscera are suspended in front, and to which heavy legs are attached below, we carry an extremely delicate and sensitive nerve structure [Fig. 33]. This nerve structure, called the

spinal cord, is enclosed in the spinal column like a candle in a lantern. It divides into many dozens of nerve fibres that accompany the spinal cord

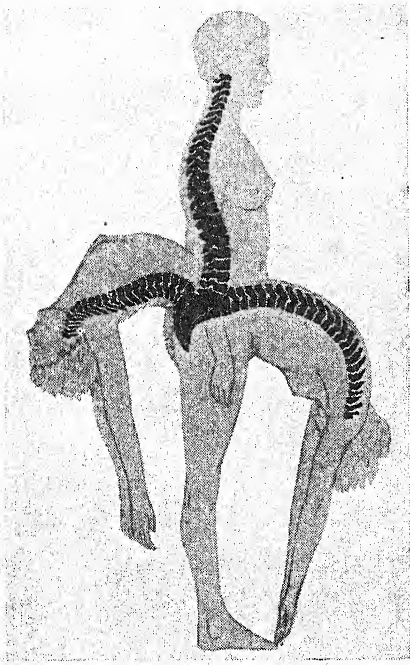


FIG. 61. *The flexibility of the backbone. Despite its strength the backbone can be bent like a bamboo stick. The spinal cord is suspended within it (Fig. 33) without being injured, or without our even knowing that it is there—a most daring technical achievement, an ingenious solution of a mechanically difficult problem.*

within the canal of the vertebral column and pass out between the vertebræ. We can jump, ride on rough roads, and engage in strenuous sports like boxing without anything happening to the spinal cord, so that many people pass through life without ever having learned that there is a spinal cord in the backbone.

Curvature of the Spine. There are few people with ideally curved spines. On the contrary, everyone deviates to a greater or lesser degree from the technically ideal form. The three most frequent deviations are:

1. The round back—the result of an extreme posterior thoracic curvature.

2. The hollow back—due to an extreme form of the anterior lumbar curvature.

3. Lateral deviations of the spinal column from the perpendicular, a condition called scoliosis.

The frequency of curvature of the spine is due to various causes:

1. Defective accommodation of the individual to an erect posture. The erect posture of the body is a relatively recent acquisition, and the body is not yet satisfactorily adjusted to the new demands arising out of this altered situation. The mechanics of the erect body are technically unfavourable and the spinal column cannot yet satisfy these demands.

2. Congenital weakness of the ligamentary apparatus. In many families the individuals suffer from a congenital weakness of the connective tissue and the ligaments. The members of such families tend to have varicose veins, hernia, flat feet, and curvature of the spine.

3. Overburdening of the spinal column during childhood. In many families and occupational classes the children begin to work too early at home or in the business world, and generally at tasks far beyond their physical capacities. To be sure, the parents are proud of the child's achievements, but in many cases the spine suffers as a result. Tasks that demand the continued use of one side of the body, such as carrying water, selling newspapers, the carrying of small children by older sisters who themselves are still children,

and the like lead to excessively prevalent lateral curvatures, scolioses.

4. Habitual postural errors. Many activities lead individuals to assume poor postures. Among these activities writing is very important.

5. Deterioration of the spinal column. In order to remain capable of functioning, an organ must be kept active. It should be neither overtaxed nor condemned to inactivity. The spinal column of modern man works too little. Modern man spends half his life or even longer sitting at a desk, a sewing-machine, a workbench, or the wheel of a car. There he sits without moving and cramps his spine into one position. After his work is over he relaxes, and again he sits in an armchair or in a well-upholstered car, or he reads, listens to the radio, plays cards, or takes a nap in an easy-chair. This unhealthful mode of life already begins during childhood. In school the pupils sit for many hours in their seats. On the one hand, this is an excessive burden for the child's spine since it must carry the weight of the head, which is still quite heavy in schoolchildren, throughout the entire period of instruction. On the other hand, the spine is inactive for too long a period, because as a result of sitting continuously in one place the spine becomes cramped without having any possibility of movement. Instruction should begin every morning with some form of exercise and end in the same manner at noon. The best form of exercise for the spinal column is the carrying of objects on the head. Children should be taught to do this because they will certainly practise it with great pleasure. The balancing of objects on the head forces all parts of the spinal column, even the smallest and most delicate muscle groups and the most secluded ligaments, to become active and to respond rapidly to stimuli. Nowhere can one see individuals with such good posture, such graceful movements and healthy spinal columns as in those countries where the women carry their baskets and jars on their heads.

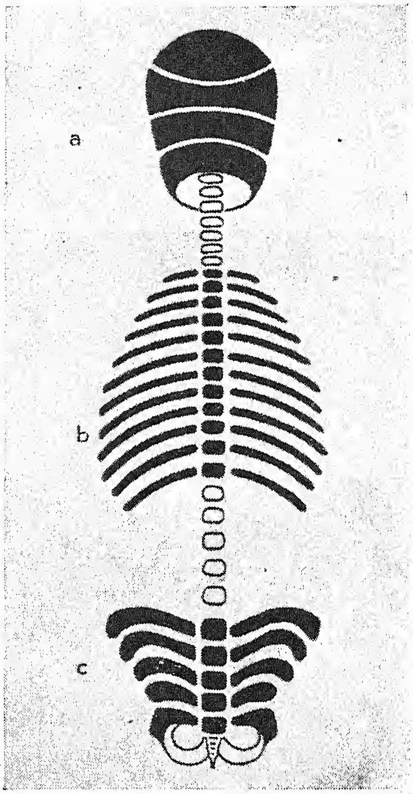


FIG. 62. *Diagram of the skeleton of the trunk: (a) the skull; (b) the thorax; (c) the pelvis. These groups of bones are all attached to and supported by the spine.*

The Thorax. Consider the development of the skeleton as depicted in Figure 23. At first the spine is actually only a spinal column. Later, however, it becomes a structure for the protection of the soft parts and

envelops the spinal cord on the one side and the viscera that are suspended from it on the other. Of these enveloping bands the four anterior ones grow together to form the most primitive part of the skull, the middle twelve form the thorax, and the posterior five the pelvis. Skull, thorax, and pelvis are the three "outgrowths" of the vertebral column.

Development of the Chest

In animal bodies supported horizontally on four legs, the viscera are suspended from the backbone like washing on a line, as said before. Consequently the three outgrowths, skull, thorax, and pelvis, are narrow and point earthwards. But in man, whose body stands upright, the loads of the skull, thorax, and pelvis are differently distributed so that they have developed as broad, round basins. A round head, a broad, freely rounded chest, and a broad bowl-shaped pelvis are three characteristics that differentiate man from beasts. No animal has such a widely arched skull. Nor has any animal a pelvic "bowl" like that of man, and even less like that of the human female, which is predestined for the function of child-bearing. At birth both the chest and the pelvis of the child are still narrow and reminiscent of the animal form. A child, which is indeed still a "quadruped" at birth, comes into the world with a "dog's chest." It is less than four inches deep and a little more than four inches wide. Not until after the onset of puberty, between the ages of fifteen and thirty, does man expand laterally and acquire a specifically human chest, which then becomes about nine and a half inches deep and a little over fourteen inches wide. The ratio 10:11 becomes the ratio 10:15. The structural dimensions of the skeletal portions of the female trunk (thorax-pelvis) surpass those of the male, for the female body, in view of the child-bearing function, must be relatively more roomy than that of the male. Consequently the female thorax is wider, just as the cover of a large pot must be larger than that of a small one [Fig. 63].

The Ribs. The bony bands which the vertebral column sends forth anteriorly to close the thoracic viscera are called ribs. The number of ribs decreases the higher one ascends in the mammalian group. The most primitive anthropoid, the gibbon, has fourteen; gorilla and chimpanzee have each thirteen; the orang-utan, like man, has twelve pairs of ribs. During the early part of his embryonic life man has thirteen pairs of ribs—probably a relic of the past. In six per cent of human individuals this thirteenth pair of ribs persists even after birth.

Breathing Exercises

Anteriorly, in the mid-line of the body the ribs are united by a broad plate of bone which points downward like a dagger suspended from the neck. This is the breastbone or sternum. The ribs are attached to the sternum by means of the costal cartilages. These cartilages are elastic, thus aiding in the expansion of the chest during inspiration. The circumference of the human chest is in part dependent on the manner of breathing. Since the thoracic cage contains a good deal of cartilaginous tissue and is mobile, it is easier to influence it by means of exercise than any other part of the skeleton. If a young man engages in athletics the circumference of his chest increases. The most rapid increase is achieved

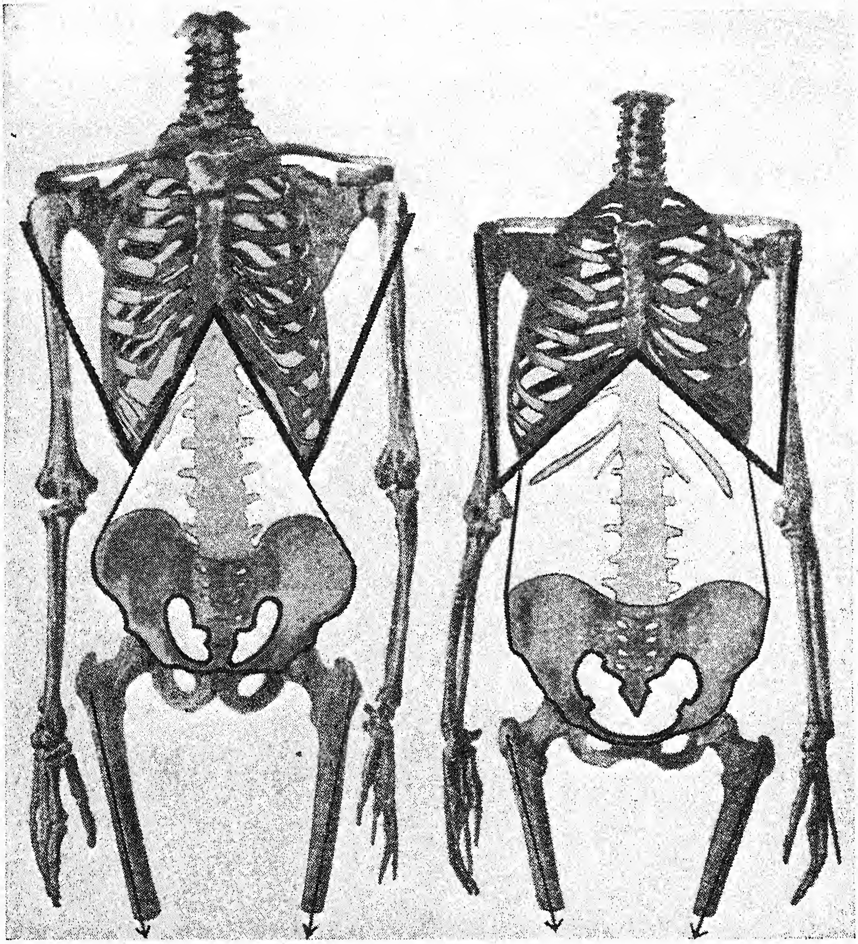


FIG. 63. *Male and female skeletons. A man (Left) has a narrower thorax, but a more powerful shoulder girdle, a narrower pelvis (and consequently a narrower and smaller abdominal cavity) than the woman (Right). The heavy black lines clearly bring out these differences between the male and the female skeletal structure.*

by means of rowing. In this sport the thorax is actively distended by the pull of the muscles of the arms and the chest, and it also demands the greatest amount of respiratory activity on the part of the body.

Naturally, breathing exercises and correct methods of breathing also favour the growth of the thorax. In schools, instruction periods should be interrupted for several minutes during which the pupils can straighten out the vertebral column and expand the chest by deep breathing [Fig. 64].

The Pelvis. The possession of a genuine pelvis—that is, a bowl-shaped container for the viscera—is a prerogative of mankind. If a beginner in the study of biology be asked to indicate the most striking

differences between animal and human skeletons, he will almost always point to the skull or the hand. Neither example is quite conclusive. By far the most characteristic structure of the human skeleton is the pelvis, and in no part of the skeleton is man so far removed from the

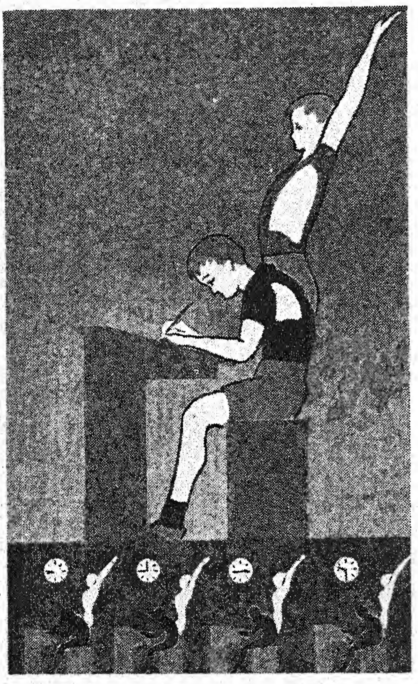


FIG. 64. *Breathing exercises performed during school hours in up-to-date schools prevent narrow-chestedness and pulmonary maladies, by expanding chest and lungs.*

animals as in this. The general attitude of contempt and belittlement with which this part of the human body has been regarded in human society is entirely unjustified. Woman has surpassed man in the evolution of the pelvis. In this matter she is more " human " than man. Man has surpassed woman, however, in the size and shape of the skull. Man is a " skull " creature, woman a " pelvis " organism. In the human species, as in all other animal groups, nature has instituted a division of labour between the sexes. Woman's chief biological function is the bearing and raising of children, while man is destined by nature for other activities. Perhaps the future development of civilization will free woman from this task, and lead to new developments in this aspect of human life as in so many others.

Differences of Sex

Comparison of the male and female skeletons renders their differences very obvious, especially if one has spent some time in examining the picture and studying the details [Fig. 63]. In the female the shoulder girdle is less strongly developed, while the abdominal cavity is much more roomy. The internal dimensions of the female pelvis, in particular, are much wider than those of the male, for it is through this bony passageway that the child passes on its way from the mother's body to the external world. If a woman's pelvis is pathologically narrowed, the child may have great difficulty in being born, or birth by way of the natural passages may even become impossible [Fig. 65]. If the possibility of a natural birth exists, but the woman's own powers do not suffice to expel the child, it must be extracted through the narrow pelvis by a physician, with the aid of the obstetrical forceps. If it is impossible for a natural birth to take place, the child must be removed from the mother's body by Cæsarean section—that is, by opening the abdominal wall and incising the uterus. It is reported that the kings of certain African Negro tribes in inspecting their prospective brides are less con-

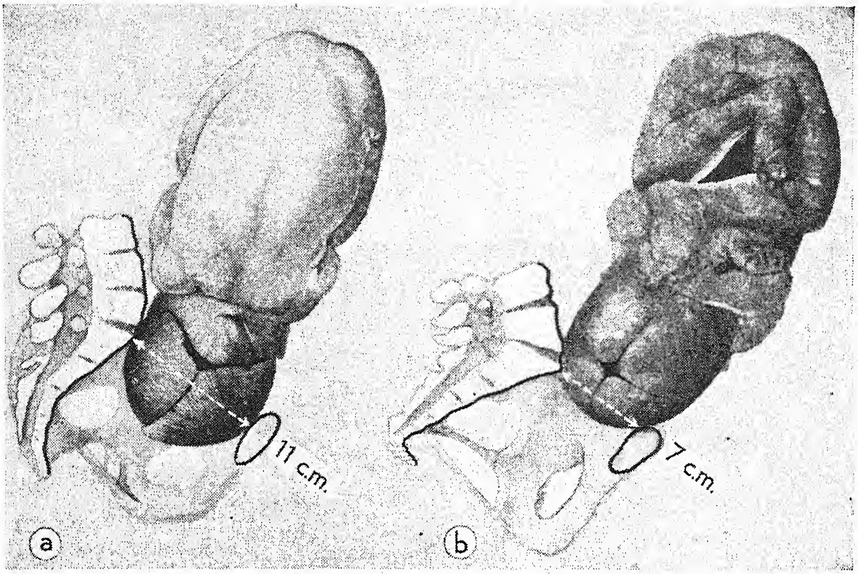


FIG. 65. *The significance of the pelvic measurements for mother and child: (a) when the pelvic dimensions are normal the child is able to pass through the pelvic canal at birth and thus leave the mother's body; (b) if the pelvis is contracted the child is unable to pass through it and must be removed from the mother's body by a Cæsarean operation.*

cerned about the frontal appearance of these women than about their appearance from the rear. This posterior inspection is not so comical as it may appear to us. A woman with a narrow pelvis is actually not suited for marriage. Consequently the general physical examination which should precede every marriage ought to include an examination to determine whether the woman has a pelvis of normal dimensions and is capable of giving birth to children in a normal manner.

The Arm and Leg. The structure of the arms and legs corresponds like a picture and its mirror image [Fig. 66]. These paired appendages are composed essentially of a bony tripod, the girdle, which anchors the limb to the backbone, a long bone known as the humerus or femur depending on its location in the arm or leg respectively, then two bones situated side by side, called radius and ulna in the arm and tibia and fibula in the leg, and finally a number of small bones composing the wrist or ankle, and the hand or foot. In the quadruped ancestor of man, before he assumed an upright position, both performed identical functions. As a result of the change in posture, however, their functional development has been in diametrically opposite directions. The leg became a bearer of burdens, while the arm became a free artist. The arm was freed of its former duties, which were now assigned to the leg. The arm is attached to the body by means of the shoulder-girdle, the leg by means of the pelvic girdle [Fig. 63]. The parts of the girdles are homolo-

gous; that is, each bone has its counterpart in the corresponding girdle in front of or behind it, as the case may be. The elevated shoulder-girdle is light and of a much more flexible construction, while the lower pelvis is heavy, strong, and firmly fixed to the axial skeleton. The arm hangs freely from the shoulder; the leg is fitted deeply into the pelvis like a supporting pillar. The leg supports and carries, while the arm is carried. Under the burden of the trunk the legs have become arched in their upper portions, the neck of the thigh-bone thus forming a supporting arch beneath the hips. The bones and ligaments composing this arch are the strongest in the entire body. Owing to the great load which they carry, the necks of the thigh-bones are the most vulnerable points of the skeleton. In children they are frequently attacked by disease (tuberculosis of the hip-joint), and they are easily fractured in old people (fracture of the neck of the femur).

The knee-joint is the strongest of all joints, while the elbow-joint is functionally the most versatile joint in the body. The knee-joint is

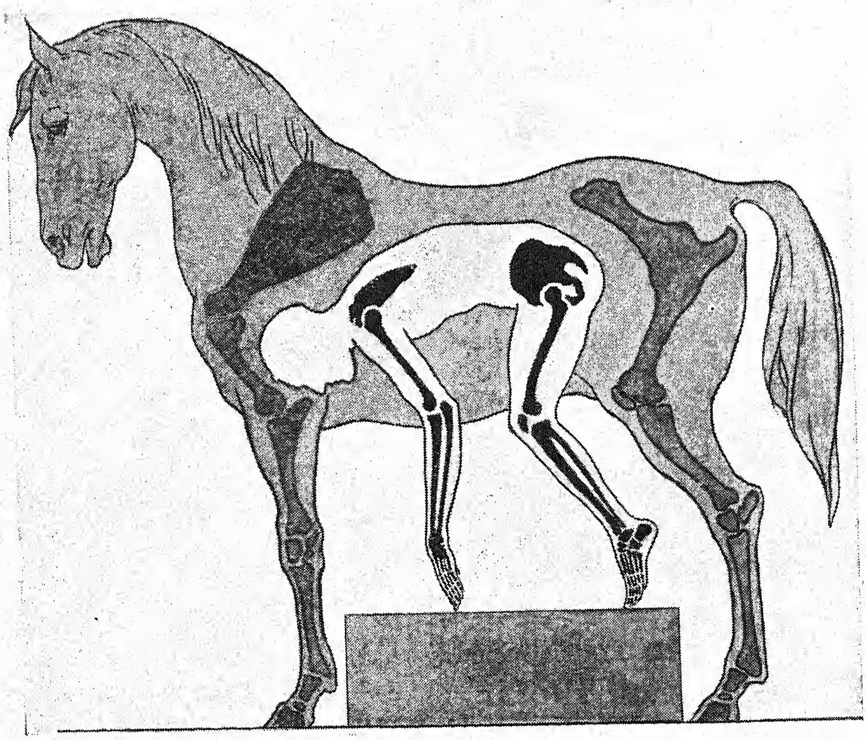


FIG. 66. *The arms and legs are homologous in their structure; that is, they consist of corresponding segments. They correspond to the limbs of other mammals even when, as in the case of the horse, the animal has another type of walk. A horse stands on the tips of its middle fingers and has its knee-joints in the body. In the case of whales and seals the corresponding bones are found hidden in the fins.*

governed by ten muscles, held together by ten ligaments and surrounded by thirteen mucous bursæ [Fig. 47]. In front it is protected by the patella (knee-cap) like a shield. In its interior are two cartilaginous, approximately semi-circular disks that serve to deepen the surface of the head of the shin-bone for articulation with the thigh-bone. They assist in restricting the area of motion of the articulating bones, so that they cannot slip away from each other and become disjointed.

Acrobatics

Let us try to grasp the actual significance of the fact that man stands erect! [Fig. 67]. On the floor rests the foot with its domed arch (a). On this arch the stilt-like shin-bone is balanced (b). Above the shin-bone, the thigh-bone, with a knob at one end and thus resembling a walking-cane, is balanced at the knee-joint (c). On the spherical handle of this cane the pelvis is balanced (d), and above the pelvis rises the spinal column with its thirty vertebræ (e). Upon the uppermost vertebra the large sphere of the skull is balanced. This structure stands erect! It can jump, and even perform knee-bends (II). Just imagine what people would say if an acrobat were to balance spheres, stilts, canes, and a column of thirty small cubes in such a manner that the entire structure could imitate a knee-bend!

The elbow-joint is a masterly construction, too, but of a very different type. The knee-joint is adapted for strength and the function of locomotion, the elbow-joint for freedom and flexibility of movement. The elbow-joint is not a simple hinge-joint like that of a finger or a pocket-knife, but is combined with a pivot-joint between the two bones of the forearm. If the arm is extended with the palm up and the shoulder-joint kept steady while the hand is rotated

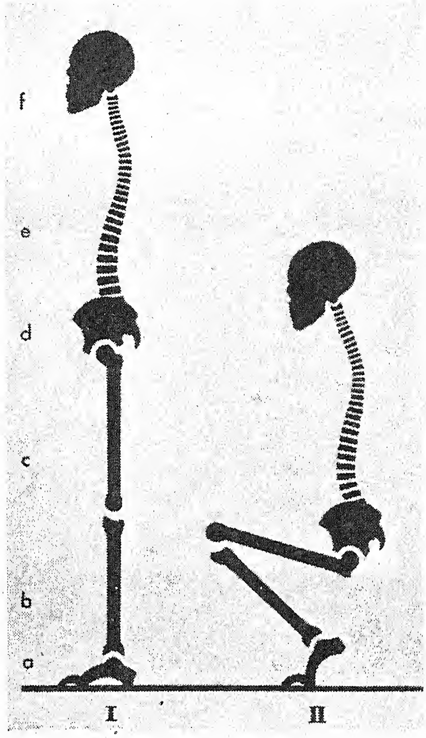


Fig. 67. *The human carriage (I) and gait are highly artistic achievements, even from the mechanical point of view alone; a knee-bend posture as in (II) is a masterpiece of poise and articulated balance.*

until the back of the hand is turned upwards, it can be observed that one bone (radius) of the forearm rotates about the other (ulna). It is this joint that is employed in all rotary movements of the forearm—for example, opening locks, turning the pages of a book, or uncorking bottles.

The Hand. The view that the human hand is the "greatest achievement" of mankind is a general and

widespread error. Exactly the opposite is the case. In contrast with most other parts of the human body, the hand has remained a rather primitive part of the skeleton. As animal's mode of life. The hand of the ground-hog has become a digging tool, that of the elephant an instrument for stamping. Man, however, has retained the ancient five-

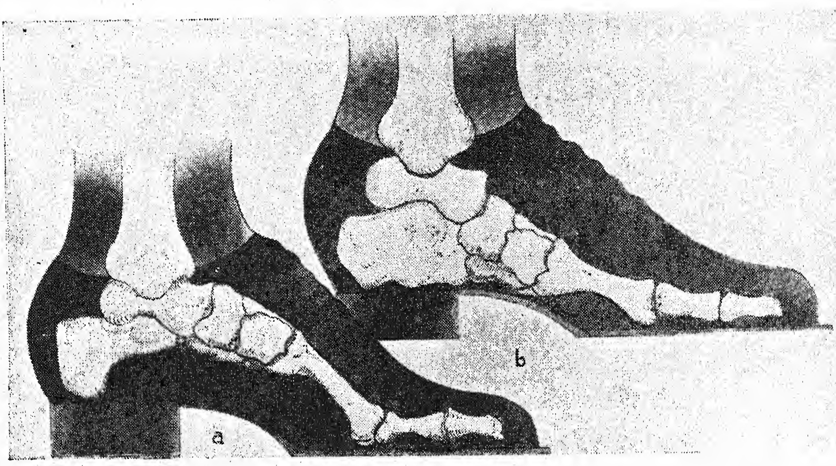


FIG. 68. *The normal foot (a) is an elastic arch. If this arch drops under the weight of the body the result is a flat foot (b). Compare with Fig. 69, where a simple method of testing the condition of your arches is illustrated.*

fossil remains indicate, the primitive batrachians, from which all land vertebrates are derived, had a five-fingered "hand." From these creatures developed higher animals that lived many millions of years ago during the Permian period and left behind "footprints" that are not footprints at all, but rather hand-prints. For this reason these extinct animals have been named Cheirotheria, "Hand-animals." At that time the ancestors of most modern mammals—for instance, primitive horses, predatory animals—still had genuine hands.

In the course of history almost all animal species have specialized their hands. In birds the hand has become a wing, in the horse a hoof, and in the lion a paw. In each case the hand has been well adapted for the fingered hand. The only specifically new human acquisition is the "apposition" of the thumb. The thumb has wandered away from the other fingers and has assumed a position of apposition in relation to them. If the hand is opened and closed its specifically human quality is immediately apparent. In closing the hand the inner surface of the thumb approaches the other fingers. It is this circumstance that has differentiated the human hand from related structures in animals and made it into an organ literally capable of "comprehensive" achievements. The apposition of the thumb and the fingers is one of the few specifically human characteristics of our body.

The Foot. The foot differs from the hand in that the bones between

the heel and the toes are arranged in the form of an arch. While the corresponding portion of the hand (the palm and back of the hand) has assumed a secondary role in its function, just the reverse has taken place in the development of the foot. The tarsus or root of the foot, comprising the bones between the heel and the toes, has become of primary functional importance, while the toes have degenerated. Originally the tarsal bones were situated next to one another in a horizontal plane like the corresponding bones of the hand. As a result of the action of the formative forces brought into play by the weight of the body, however, they have been transformed and rearranged so that at present they form a pyramid, the base of which has been hollowed out to form an arch. This latter feature is the most representative characteristic of the foot [Figs. 50, 67, 68].

The foot is a tripod, for it stands on three points: the heel at the back and two supporting points in the ball of the foot. Over these three points the foot forms an arch which is elastic and springy owing to its special construction—that is, the arrangement of the bones, cartilages, joint capsules, ligaments, tendons, and muscles. From a technical point of view springy arches are the best type of construction for structures that have a supporting function. The space immediately beneath the arch is filled with fat. Through it pass the blood vessels, nerves, and tendons of the toes without being squeezed during walking.

Man is a child of nature, and as long as he went about barefoot outdoors he was probably unacquainted with any foot maladies; for the irregular and resilient character of the natural soil forces the foot to assume a new attitude and a new state of tension with every step. Under these conditions the entire foot, including the most delicate muscles and ligaments of the arch, are compelled to be active, with the result that all parts of this organ are well exercised. On the smooth city streets and hard floors of our houses, however, only a few identical points of the foot are repeatedly stimulated and put under tension. The result is that the foot adapts itself in a specialized manner to these uniform stimuli. It remains in a state of spastic tension. This spastic state produces a disturbance of nutrition;

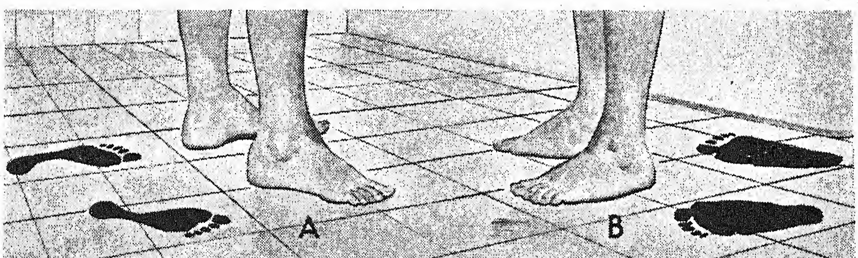


FIG. 69. *Notice the tracks of your feet on the bathroom floor. A normal, healthy foot, with properly raised arches, leaves bean-shaped tracks (A); if the centre sole leaves an impression, the person is flat-footed (B). More than ten per cent of modern city-dwellers suffer from flat feet and consequent disorders.*

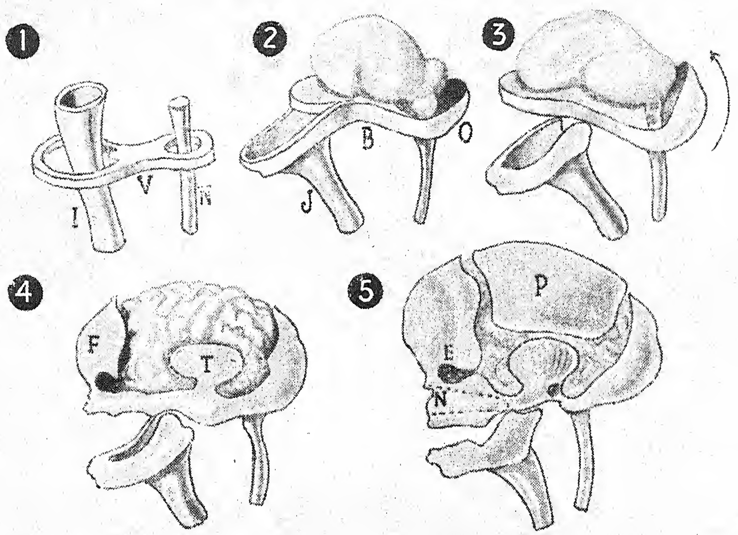


FIG. 70. *A schematic representation of the five stages in the development of the skull. (I) Intestinal canal; (V) vertebral body; (N) neural tube; (J) jaw; (B) brain; (O) occipital part of skull; (F) frontal part of skull; (T) temporal part of skull; (N) nasal portion of facial skull; (E) orbital portion of facial skull; (P) parietal skull. The process of development is fully explained in the text.*

the tissues become tired, anæmic, weak; the arch of the foot becomes unable to bear the load of the body and drops down. Dropping of the arch occurs in more than ten per cent of modern urban inhabitants, giving rise to flat feet. On stepping out of a bathtub, observe the prints made by the wet feet. If the tracks are kidney-shaped, because the inner half of the arch does not come into contact with the floor, the foot is normal. If the prints have the shape of a sole, because the entire sole touches the floor, the foot is flat [Fig. 69].

A certain number of cases of flat feet arise as a result of a constitutional disposition. The connective tissue of such individuals is naturally weak, and just as they may suffer from curvature of the spine, they are also liable to dropping of the arch of the foot. In the majority of cases, however, flat feet are acquired in the course of a lifetime either as a result of engaging in an occupation where workers are required to stand for very long periods—for example, bakers, waiters, washwomen, sales-people in stores, factory workers—or because of incorrect training and modes of life.

The Structure of the Skull. On superficial examination the skull appears inextricably complicated [Fig. 74 (I)]. Actually, however, it is built just like the thorax and the pelvis. It consists originally of two outgrowths of the spinal column, one of which grows around the intestinal tube anteriorly, and the other around the neural tube posteriorly in order

to protect these structures [Fig. 70]. The jaws have developed from the anterior arch, while the posterior one as a result of various transformations has become the bony capsule of the brain. In order for the human tower to be able to orient itself as it moves about in its environment, three pairs of sensory-organ canals have been pierced in the skull: the nasal cavity, the eye cavities, and the auditory passages. The upper part of the skull, in which the brain rests, is called the cranium; the lower part surrounding the mouth and containing the nose and the eyes is known as the facial skeleton. The cranium and the face are separated by a plate of bone called the base of the skull, just as two storeys in a house are separated by a floor [Fig. 74 (II, a—d)].

Position of the Brain

On the floor of the skull lies the brain, or it might perhaps better be described as suspended over it. The brain rests within the skull like a large cheese under a bell-jar. The plate upon which the brain rests is the floor of the skull, the jar that covers it is the cranium.

The Skull Spaces. At birth the bony plates of the skull are still very soft and separated by slight spaces. At these points the bones possess a certain degree of mobility so that they may be pushed together or even overlap one another at the edges. This fact helps to explain how during the birth of the child its relatively large head can force itself through the narrow canal of the pelvis [Fig 65 (a)]. After a difficult delivery the child's skull looks like a felt hat taken out of a trunk after a long trip. It is common knowledge, however, that a felt hat sustains such an experience without any damage. If the skull of a baby is palpated during the first few months, one can feel that the bones are as soft as cardboard, and that there are gaping spaces between them. The largest gap is situated anteriorly above the forehead, while a second is located posteriorly in the back of the skull between the occipital and parietal bones [Fig. 65]. These uncovered areas have been named *fontanelles*

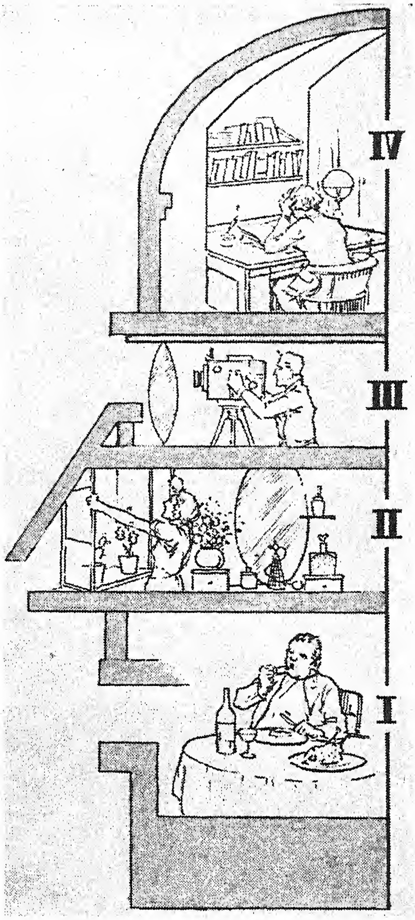


FIG. 71. *The four storeys of the skull-house: the lowest storey (I) represents the oral cavity; (II) is the nasal cavity; (III) the orbital cavities, and (IV) the cranial cavity.*

because the pulsation of the blood vessels of the baby's brain can be seen and felt through these spaces and suggest "little fountains." In the course of the first two years the fontanelles close. Functionally, they are reserve spaces; in childbirth the mobility which they permit is of great practical value, while after birth they permit the further growth of the cranium. The bones of the skull grow into and fill out these spaces, permitting the growth of the brain.

The Cephalic Index. The child's head is very plastic owing to the softness of the cranial bones and the presence of the spaces between them. The Peruvians compressed the heads of their children to produce elongated skulls. Among many primitive peoples the children's skulls are artificially deformed. The ratio of the length and breadth of the skull is designated as the cephalic index. The greater length is always considered equal to 100 and the relative width is calculated on this basis. Thus if a skull is 180 mm. long and 150 mm. wide, its index is calculated according to the formula $\frac{180}{100} = \frac{150}{\text{Index}}$. Consequently the $\text{Index} = \frac{150 \times 100}{180} = 83.33$. Skulls having a cephalic index below 75 are characterized as long-heads (dolichocephalic); skulls with an index between 75 and 80 are classed as mesocephalic; and those with an index over 80 are round-heads (brachycephalic). The shape of the skull has absolutely no significance for the evaluation of the capacities of an individual. The shape of the head can be influenced at will. According to purely mathematical principles, the human skull should actually approach closer to a spheri-

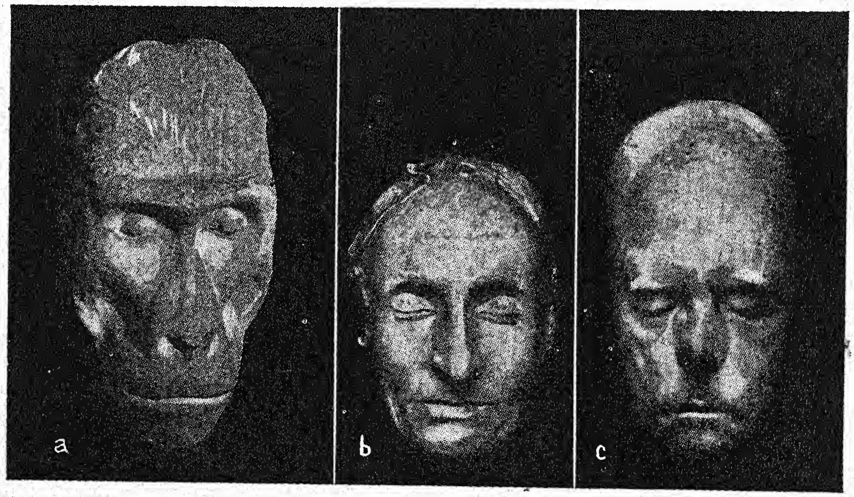


FIG. 72. *Skull types: (a) female gorilla, showing the characteristic feature of the ape skull, the relatively large facial portion below the eyes as compared to the smaller portion of the brain above the eyes; (b) the French mathematician and philosopher Pascal had a very round, flattened skull; (c) Sir Walter Scott, the novelist, had an extremely high "tower" skull with an enormously developed forehead. In human beings the shape of the skull has no influence whatever upon mental development.*

cal form as the brain grows larger, for a sphere is a body combining the greatest capacity with the smallest surface area.

However, the form of the skull not only is dependent on the type of care received during infancy, or on the growth of the brain, but is also influenced by a large number of other factors, of which in some instances little is yet known. In mountainous regions there are more long-heads, while there are more round-heads in plains districts. No connection exists, however, between the shape of the head and intellectual capacity. There are long-headed and round-headed dunces as well as long-headed and round-headed geniuses among all peoples and in all social classes [Fig 72].

The Cranial Sutures. The bones of the skull do not grow together and unite, but instead they develop zigzag edges which dovetail together in an interlocking joint [Fig. 74 (I)]. These zigzag sutures hold the bones firmly together while at the same time permitting a very slight degree of mobility. A skull can be compressed in a vice for several centimetres without breaking.

The Base of the Skull. The brain rests on the floor of the cranial cavity. The base of the skull is not smooth, but rather moulded into a very complicated, one might almost say bizarre pattern [Fig. 74 (II)]. Posteriorly it is pierced by the *foramen magnum,* a large opening into the cranial cavity through the occipital bone. Through it the nerve cable of the spinal cord passes downward from the brain to the trunk (a). In front of this hole the floor of the skull rises steeply; this part is called the slope or declivity (clivus). Laterally, on each side of the clivus running obliquely and posteriorly is a high, hard, bony pyramid, the petrous bone. Embedded in the interior of each petrous bone like sensi-

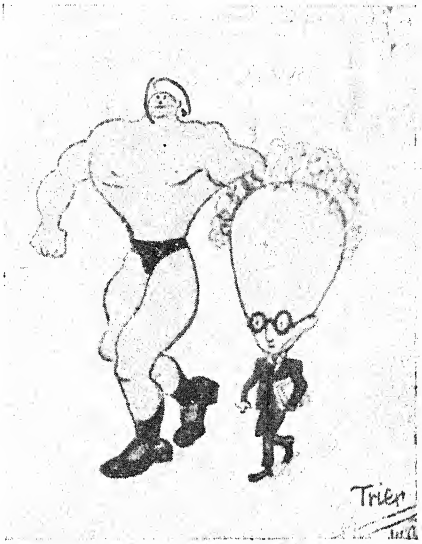


FIG. 73. *A caricature on the one-sided development of the intellectual as compared with that of the athlete. The popular idea that a highly developed forehead denotes superior mental or moral capacity has probably no foundation in fact.*

tive seismographs are the organs of hearing and equilibrium of the human head (b). Above the clivus rises the *sella turcica* (Turkish saddle) (c), in which the pituitary gland, or hypophysis, is lodged. The bone in front of the *sella turcica,* of which it forms a part, is the sphenoid bone. When considered *in toto* with its supporting parts below, its hollow body in the centre, and the two great and the two small wings extending outwards from the sides of the body, the sphenoid bone resembles an aeroplane. Anteriorly to the sphenoid rises the *crista galli* (cock's comb). On each side of this crest the bony

plates are perforated by holes for the passage of the olfactory nerves. On these cribriform plates (also known as the *lamina cribrosa*) lie the two olfactory bulbs of the brain. From these bulbs the olfactory nerves pass through the foramina of the cribriform plates into the nasal cavity.

Ancient Fallacies

Formerly it was believed by many that noxious vapours and humours of the brain flowed into the nose, and the mucus of the nose was regarded as a secretion of the brain. A cold in the head or a nasal catarrh was considered to be a cleansing of the brain, in the course of which the brain eliminated the mucus. In the process of embalming the bodies of their dead the Egyptians passed an instrument up the nose, penetrated through the cribriform plate into the cranial cavity, and removed the brain without noticeably injuring the skull.

The Human Forehead. In front of the *crista galli* rises the anterior wall of the cranial cavity as the forehead. The forehead covers the frontal lobes of the brain, the alleged seat of the intellectual and moral faculties of man. It is popularly but probably erroneously believed that the development of the frontal lobes is an indication of the intellectual and moral capacities of an individual. Consequently, it is reasoned, the more one experiences and thinks, the higher must be the forehead. This chain of reasoning is the basis for the expression: "the forehead of a thinker," often used to describe a person of intellectual attainments.

The Facial Skeleton. The part of the skull situated below and anterior to the base of the skull is the facial skeleton. It contains three cavities located one over the other, so that the entire skull may be compared to a house having four storeys: namely, the oral cavity, the nasal cavity, the orbital cavities, and the cranial cavity [Fig. 71]. In the bony skull the cavities appear remarkably large, but in the living, except for small openings, they are filled with soft tissues. In front of the orbital cavities hang the lids, the nasal orifices are enclosed by cartilages, and the oral cavity is surrounded by the tissues making up the cheeks and lips. The edges of the orbital cavities are heightened on all sides to protect the eyes. Over the eyes arch the eyebrows like the arch of a gate, between the eyes rises the profile of the nose, and on each side beneath the eyes are the prominences of the cheek-bones to ward off any blow.

Structure of the Face

Boxers will strike boldly at each other's faces, yet we rarely hear that a blow has destroyed a boxer's eye. The nose, the cheek-bones, and the brows receive the blows and are therefore the points that are usually cut and begin to bleed during a fight.

The Cavities of the Face. Externally the facial skeleton is solid; internally, however, it contains cavities by which its weight is decreased as much as possible. The human skull much resembles a house. Outwardly it appears to be a massive structure; actually, however, it is hollow, a shell with many rooms, chambers and corridors. An opened human skull also bears an extraordinary resemblance to a snail-shell. It is probably the most complicated "snail-shell" borne by any living creature. Figure 75 shows a very remarkable picture, yet it is not a fantasy. This is the appearance of the

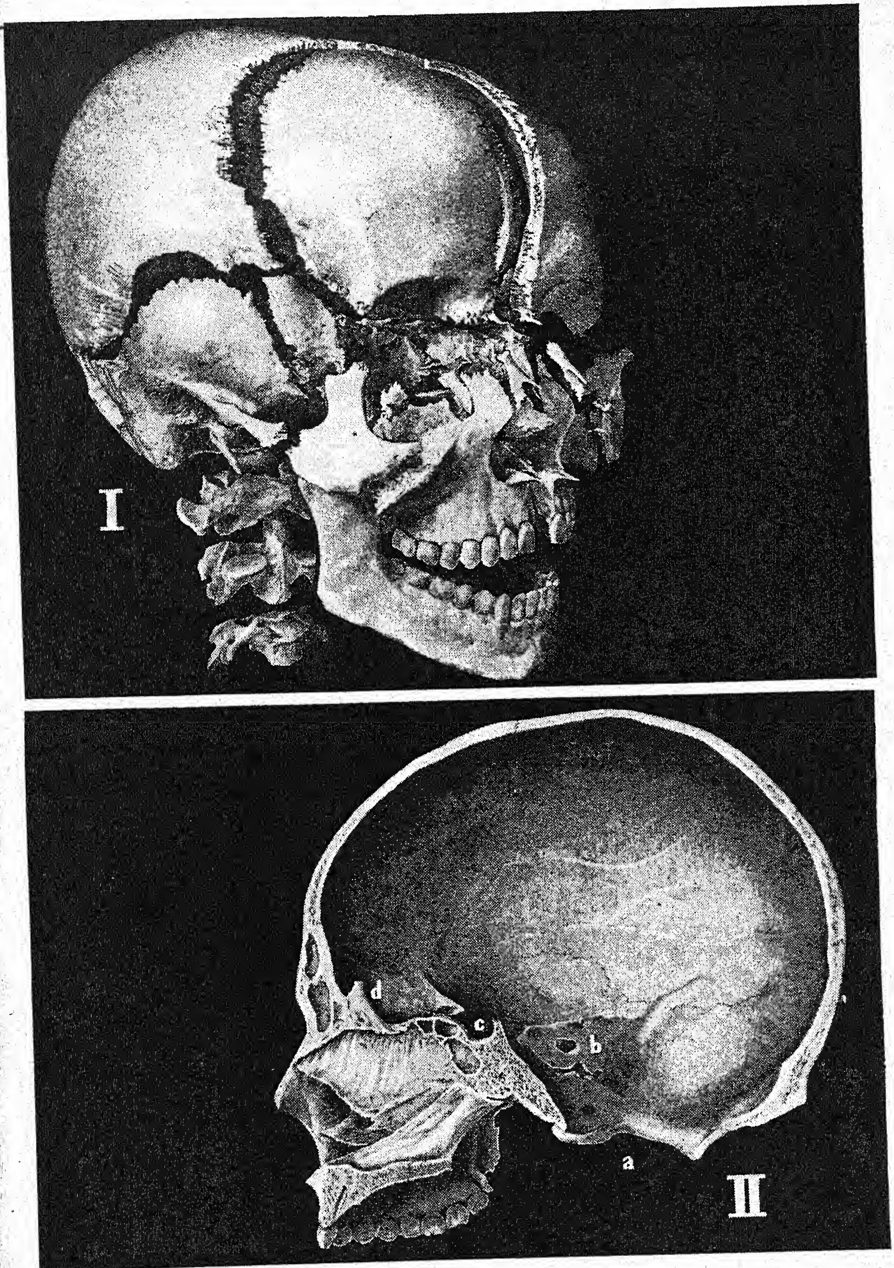


FIG. 74. *The human skull: (I) as seen from without; (II) showing the interior; (a) the foramen magnum, through which the spinal cord passes; (b) the petrous bone, which contains the auditory apparatus; (c) the "sella turcica," within which the pituitary gland is situated; (d) the cribriform plate, on which the olfactory lobe lies.*

interior of a human head behind the façade of the face covered by muscles and skin. If we could look through the skin of a human being as through a window-pane and recognize the interior of the skull, it would present this grotesque appearance. Above, behind the forehead one looks into the large cranial cavity. Beneath it lie the two orbital cavities (b), shaped like two elongated funnels that become narrower posteriorly. Between them lies the nasal region, consisting of two storeys, the lower one consisting of the two broad corridors of the respiratory passage, through which the inspired air passes on its way to the trachea (c). These two passages look like the entrance to a fortress. On the lateral walls the inferior nasal conchæ are suspended like two escutcheons overhanging the pathway below. Suspended over the gateway is the labyrinth (d), so called because

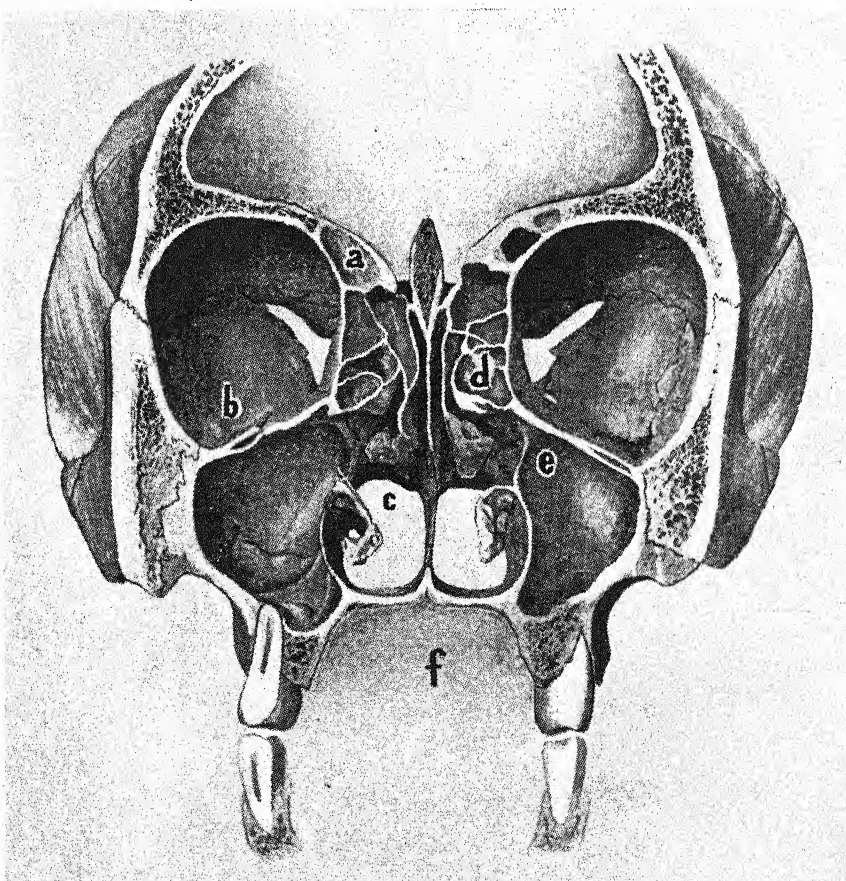


FIG. 75. *The facial portion of the skull resembles a small shell with its hollow chambers and passages, which decrease the weight of the skull and warm and filter the air as it is breathed in. Here are shown (a) the frontal sinus; (b) the orbital cavities; (c) the nasal chambers; (d) the labyrinth; (e) the maxillary sinus; and (f) the oral cavity.*

FIG. 76. *A harelip (b) is produced when the intermaxillary cleft (a) of embryonic life fails to close. This defect can be corrected by a simple surgical operation which, when skilfully performed, leaves only a barely visible scar (c).*

it actually consists of a labyrinth of numerous thin-walled cellular cavities with crooked bony walls that are closed in at every part except where they open into the nasal cavity. This labyrinth serves to warm and moisten the respiratory air. When the nose bleeds, the blood flows from the numerous veins of this structure. Laterally on each side of the nose beneath the orbital cavities are two more large cavities, the maxillary sinuses (e). Each sinus communicates with the nasal cavity by means of an irregular aperture. Through these openings inflammations of the nasal mucous membrane may wander into the neighbouring cavities, producing "catarrhs" of the frontal (a), maxillary, sphenoid, and ethmoid sinuses. As a result of these inflammations the communicating apertures of the sinuses become blocked. Mucus, pus, or both collect within the cavities, producing a sense of tension, pressure, or even severe pain. Such a condition requires medical attention for its relief.

Intermaxillary Bone and Harelip. The ceiling between the first and second storeys of the skull-house is called the palate. Three bones participate in its development. The posterior part is a separate bone, the palatine bone. The middle part belongs to the upper jaw, the maxilla. The anterior corner, which bears the upper incisors, was formerly likewise a separate bone. All animals possess this structure, which is known as the "intermaxilla." In many this bone has vanished. It is still clearly defined in the skulls of prehistoric races, but already united with the maxillary bone. In modern man the suture line between this bone and the rest of the palate has vanished, so that a single bone has arisen. At the beginning of the nineteenth century anatomists denied that man had ever had an intermaxillary bone. Goethe was of the opinion that a structure present in all animals could not have vanished completely in man. For many years he looked for this intermaxilla in all the skulls that he could obtain. Finally in an old Venetian cemetery he actually found a human skull with a sharply defined intermaxillary bone. Later during the nineteenth century embryologists also discovered, as was to be expected, that the embryo actually developed a true intermaxilla, and it is

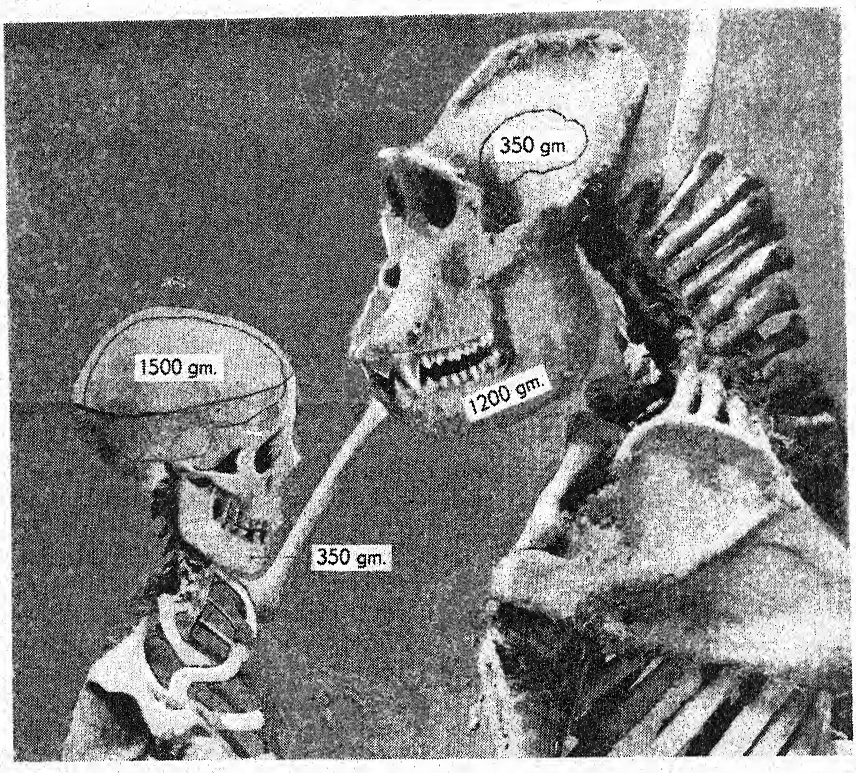


FIG. 77. *In the long struggle for survival, the weaker has conquered the stronger.*

here that the two halves of the face unite. The face is formed by the fusion of a number of bilateral processes that develop around the primitive oral cavity [Fig. 76 (a)]. If fusion fails to occur, the child may be born with the deformity known as a harelip (b). The correction of such a harelip by means of plastic surgery is one of the oldest cosmetic operations performed by man (c).

The Lower Jaw (*Mandible*). The lower jaw is the only freely movable bone of the skull. It is a classic example of the importance of work and function for the development of the human organs. In the toothless newborn the lower jaw is poorly developed. As the child grows older and begins to chew, it grows stronger, and in the adult it becomes one of the most powerful and finely moulded bones of the skeleton. Coincident with the loss of teeth in old age the lower jaw atrophies and returns to a stage resembling the more primitive jaw of infancy [Fig. 40].

Animals, not having free arms, use the lower jaw as man does his arms to perform various kinds of work. Consequently, the jaw in animals is a powerful, coarse bone. In man, owing to the upright posture of the human body, and above all to the increasing refinement of human nutrition, the work of the jaw has decreased, with the result that it has become more delicate. Among

prosimians the lower jaw weighs almost as much as the rest of the skull. Among the anthropoids its weight accounts for 40 per cent of the weight of the skull; in primitive man for 15 per cent; in modern civilized races it is only 12 per cent of the weight of the skull [Figs. 77—79]. Figure 78 shows the head of a prehistoric man with the powerful jaw of his species. Within this jaw-bone the lower jaw of a modern man has been drawn in white. What a difference! What a development towards humanity!

Man—The Speaker

A civilized man's jaw is half as large as that of his animal ancestors. In comparison with its coarse prototype it is as delicately moulded as a porcelain cup contrasted with a neolithic clay jar. Above all, modern man has a chin. The chin is a "specific" characteristic of man. No other creature has a chin. We do not know why man has developed

FIG. 78. *Primordial man had a mighty lower jaw (black). If the outline of a modern human jaw is drawn within it, one sees that in the course of its evolution it has become smaller, more finely modelled, and possesses a more pronounced chin.*

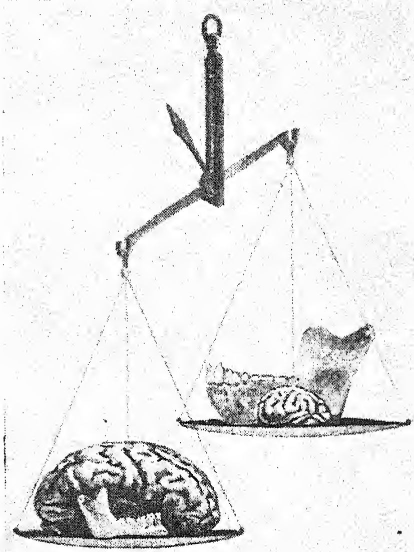
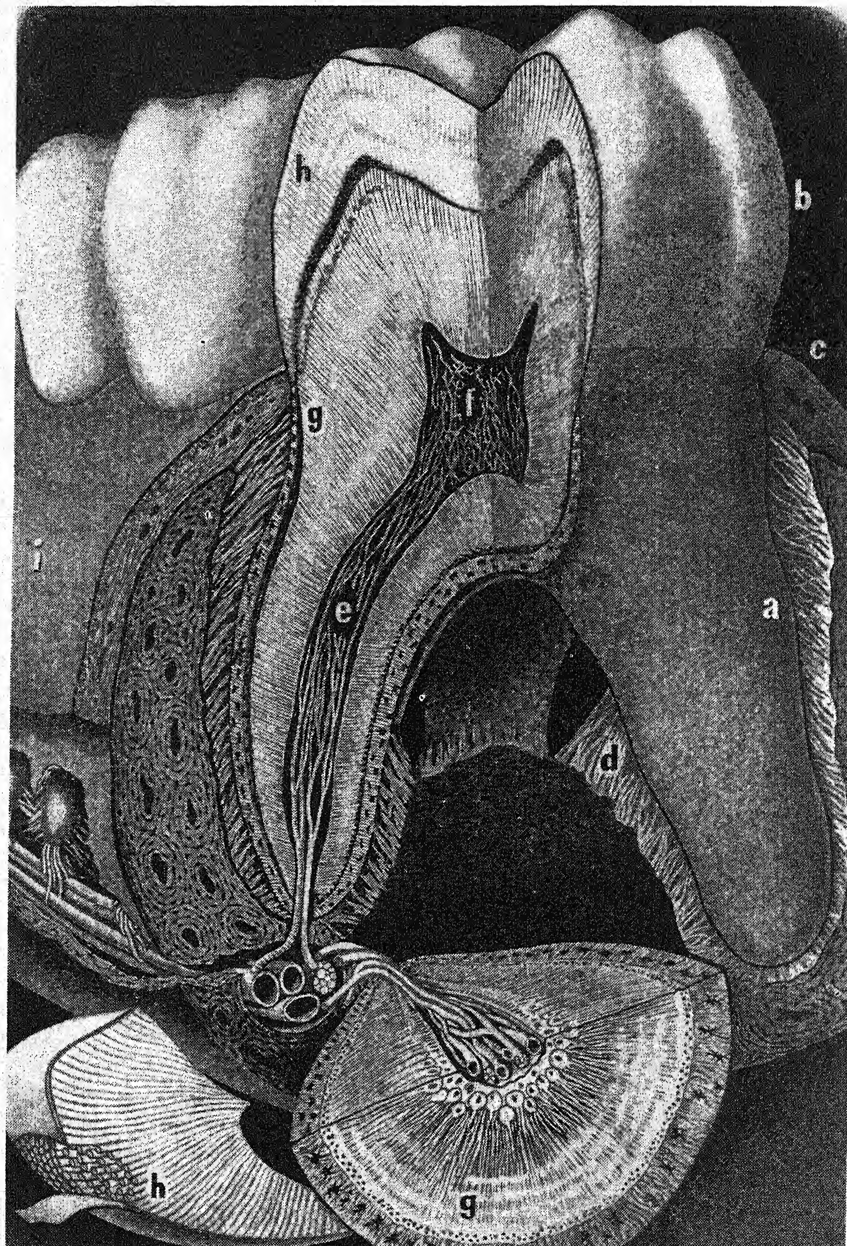


FIG. 79. *The skull of the stronger contains a brain weighing 350 grammes and a jaw weighing 1,200 grammes, while that of the weaker has a brain of 1,500 grammes and a jaw-bone of 350 grammes.*

one. Perhaps the chin developed as a result of the movements performed by the mouth in speaking, for the chin is not a characteristic of man as such, but rather of man the speaker. As seen in the illustration, primitive man, of whose capacity for speech we are ignorant, had no chin. The development of the lower jaw to its modern human form is therefore not simply a decrease in the size, but rather a transformation of this organ from an animal eating-and-biting apparatus operated by brute force to a supporting structure for the human mouth. Man no longer bites and eats like an animal, but partakes of and enjoys his prepared food in a "decorous" manner. And instead of gnashing his teeth, he utters words. The history of the lower jaw is the history of human development.



THE HUMAN TOOTH

FIG. 80. *The diagram shows: (a) root; (b) crown; (c) neck; (d) root-sheath; (e) root-canal; (f) cavity (containing the pulp); (g) dentine (or "ivory"); (h) enamel; (i) gum.*

CHAPTER VII

The Teeth

THE HUMAN TOOTH—A FISH SCALE. THE DENTAL ROOT. THE PULP CAVITY. THE WALL OF THE TOOTH. ENAMEL. REPLACING TEETH. THE DENTAL FORMULA. THE WISDOM TEETH. DENTAL DISEASES. CARIES. ANOMALIES IN THE POSITION OF THE TEETH.

AMONG a thousand people there is probably hardly one who knows what a human tooth is. The human tooth is a transformed fish scale [Fig. 81]. The primordial fishes from which modern vertebrates are descended were covered by primitive projecting scales like their modern relatives the sharks, dogfishes, and rays. Scales of this type are described as placoid, and in structure consist of a flat, basal plate embedded in the skin and carrying a projecting spine, as may be seen at (a).

Evolution of the Teeth

During the course of evolution, a division of labour appeared among the descendants of the ancestral fishes. The placoid scales that were situated in the skin outside the head lost the projecting spine but retained the basal plate. They became the scales of modern fishes, snakes, and lizards, and are to be seen in a vestigial form in terrestrial animals—for instance, the scales of a mouse's tail. However, the scales located on the jaws were employed to hold and tear the animal's prey, so that the projecting spines developed enormously in comparison with the basal plate. In the course of time they became teeth (b). A shark's scale and a human tooth correspond completely in their basic structure. Whoever describes a shark's scale is describing a human tooth, and conversely anyone describing a human tooth is likewise describing a shark's scale.

The Dental Root. A tooth is thus a projection of the skin which has entered into an intimate union with the skeleton, in particular with the jaw, so as to obtain support. The part situated within the socket of the jaw is known as the root [Fig. 80 (a)], the portion projecting beyond the gums is the crown (b), and the waist-like indentation separating the two first-named parts is called the neck (c). The teeth are not embedded in the jaws like plants in the earth, but rather like buried flowerpots. Each tooth is fixed in an individual "flowerpot" of bone, the socket of the tooth, and is united with its wall by means of the cement, a bone-like substance, and the coarse fibres of the root-sheath, or dental periosteum (d).

Structure of a Tooth

This sheath and wall of the socket contain numerous nerve fibres so that besides their mechanical function they form a sensory pad which registers any pressure exerted on the tooth. If the periosteal nerves are stimulated, the local blood vessels dilate and transport an increased quantity of blood to the tooth; that

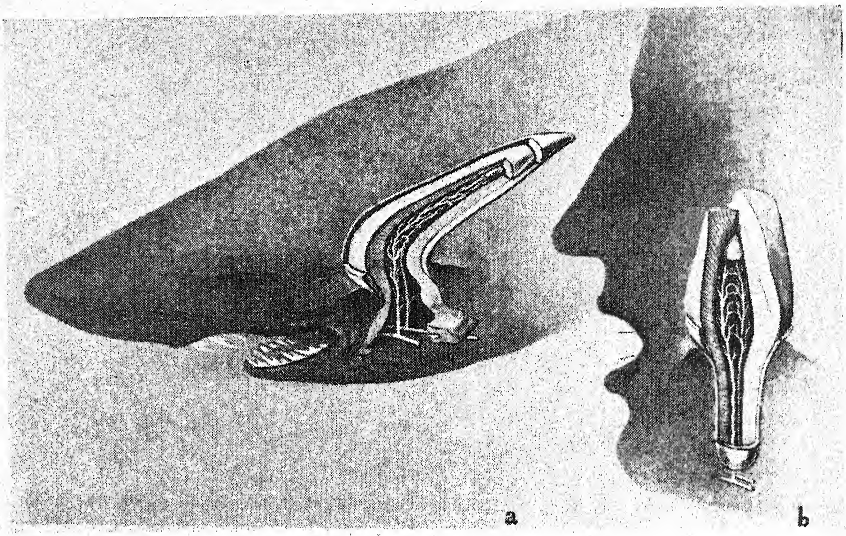


FIG. 81. *Teeth are projections of the skin which for support have united intimately with parts of the skeleton. The human tooth is derived from a fish scale, and corresponds structurally to the scales of certain primitive fishes, such as sharks and dogfish.*

is, the more stimuli a tooth receives, the better is its nutrition. If an individual partakes of a moderately coarse diet, which compels him to chew well, his teeth become stronger. If he subsists only on soft food, his teeth remain inactive and atrophy. Children at all ages should receive a well-balanced diet so that they will develop strong, healthy teeth.

The Pulp Cavity. Through the root canal (e), a passage remaining open at the base of the root, the cavity of the tooth is pervaded by blood and lymph vessels and by nerves. It is this root canal that the dentist examines, cleans, and fills with disinfectants before filling the tooth. By way of the root canal the blood vessels enter the cavity of the tooth (f), which is filled with a spongy tissue, the pulp. Within the pulp cavity the ascending vessels coming from the root branch out to form an elaborate ramifying vascular net. The minute delicate branches then unite to form a descending vessel which passes out of the tooth by way of the root [Fig. 82]. In the course of this circulation the cells of the pulp are supplied with the various substances necessary for their existence. Alongside of the blood vessels, there is a similar distribution of lymph vessels, which secrete lymph so that all parts of the pulp cavity are bathed by this fluid. The pulp cavity may be likened to an aquarium in which the vascular tree stands like a coral, while the connective-tissue cells float about like medusæ, or crawl around like starfishes, and whose walls are covered with polyps extending their long arms into the canals of the dental wall.

As delicate as those of the blood and lymph vessels are the ramifications of the nerves which torment us so much when we have a toothache, make us cognizant of heat or cold,

and transform the dentist's drill into an instrument of torture. Yet these nerves are not our enemies as we may believe; on the contrary, they are the guardians of health. They inform us of the fact that the interior of the tooth is no longer hermetically closed and sterile. Let us be thankful for the existence of a toothache. Without our toothaches we should be toothless before the age of thirty!

The Wall of the Tooth. The principal mass of the tooth is composed of a bony substance known as dentine. The cells of the dentine are attached to the walls of the pulp cavity like barnacles to a harbour wall. They extend long arms that pass through the wall of the tooth, and like the bone cells secrete fibres of gelatine and calcium [Fig. 80 (g)]. The extended fibres are situated in circular fashion around the cavity of the tooth like the spokes of a wheel around its axle. The calcium-gelatine fibres form a delicately woven network. It is this tissue that we call dentine and that forms the principal component of the wall of the tooth.

Ideal Haven for Bacteria

Ivory, as is well known, is simply the dentine of the elephant tooth. However, one need not travel to Africa to find ivory. Every one of us carries around two dozen small ivory pegs in the form of our teeth. In order not to be compressed by the secreted dentine mass, the extended cellular processes also secrete a hard homogeneous glassy shell which forms a capsule around the cell fibre and is known as the dentine canal. Each cell process lies in its dentine canal like an electric cable in its protective casing. Actually it does not lie but floats, for the dentine canals are filled with fluid. This fluid supplies the dentine fibres with nutriment; and—if they have once penetrated into the tooth—makes an ideal culture medium for bacteria.

Enamel. On its outer surface the crown of the tooth is covered with enamel as a finger is by a thimble (h). Enamel is a reinforced form of the integument. The skin cells have solidified into long prisms. They are shaped like pencils, and, like pencils in a box, lie in parallel rows alongside one another. These prisms are hexagonal in shape and are termed enamel fibres or enamel prisms. They are united in bundles by means of a cement-like substance.

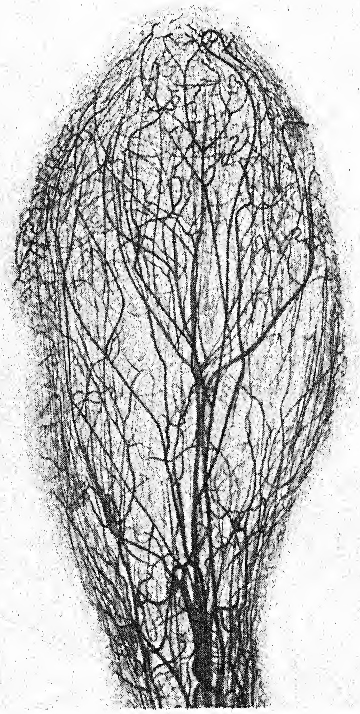


FIG. 82. *Vascular tree of the dental cavity. In its interior each tooth has a vascular network like that shown in the above illustration. The branches unite into larger vessels, which pass through the root.*

To prevent this calcific cement from being affected by the acids of the oral cavity and the food, the free surface of each prism bundle is covered by a firm resistant layer, the so-called dental or enamel cuticle. The enamel has no nerves or blood vessels and is the hardest, most compact tissue of the entire body. Chemically it consists of phosphate of lime, fluoride of calcium, carbonate of lime, phosphate of magnesium, as well as traces of other salts. We know by experience that the enamel of a tooth lasts throughout an entire lifetime if properly cared for.

Our Dental Equipment

If this were not true, we should not believe the body capable of producing a substance which, without being nourished or replaced, is capable of standing harsh treatment ten times daily for seventy long years without succumbing; which may be exposed in rapid succession to such diverse foods as hot coffee, cold lemonade, hard chocolate, bread crusts, vinegar, spiced pickles, hard fruit seeds, or rough meat fibres; which at each meal is struck and rubbed a thousand times, and yet is not destroyed. On the contrary, the teeth become healthier as a result of use. But this is the way of life, which has very different laws from those that apply to inanimate matter.

Replacing Teeth. Among lower vertebrates there is a succession of teeth throughout life. This condition is best seen in sharks, where the reserve teeth are arranged in diminishing rows reaching from the edge of the jaw to the placoid scales of the integument. When the teeth are fully developed and used up, they fall out, like hairs, and new ones take their place. Among higher animals the number of teeth and the frequency of their succession diminish. It is conjectured that the common ancestor of the vertebrates had sixty teeth. In man there is only a single replacement, the permanent teeth following upon the milk teeth. Very rarely a third atavistic replacement may be observed. At birth a human infant is edentulous—that is, without teeth. After six months the first teeth appear anteriorly in the centre of the lower jaw, and in the course of about two years a total of twenty teeth appear [Figs. 83, 84]. These are known as the milk teeth. Beneath these milk teeth rest a second series of teeth that begin to erupt after the age of six, so that the former are replaced between the ages of six and twelve [Fig. 84]. In addition to these, however, three more teeth, the molars, erupt on each side in the posterior part of the jaw, so that an adult has thirty-two permanent teeth in place of the twenty milk teeth.

Varieties of Teeth

The anterior teeth are simple teeth; the posterior ones have developed as a result of the fusion of several simple teeth and consequently exhibit surfaces with several tubercles, as well as multiple roots. The form of the teeth depends on the feeding habits of the bearer. The teeth are influenced by nutrition so that their configuration permits us to draw conclusions as to an animal's mode of life. Not only can the mode of life of extinct animals be recognized from their dentition, but even the character of the contemporary plant world can be reconstructed, and equally far-reaching conclusions can be drawn regarding the no longer existing digestive organs of these

FIG. 83. *The first milk teeth erupt at six months, the others following as shown. In the course of about two years a total of twenty milk teeth have appeared.*

animals. An animal that tears off plant leaves develops its anterior teeth for cutting purposes and carries incisors. In an animal that chews herbage or seeds the posterior teeth become flattened and broad for grinding. A carnivore, however, develops prominent canines to hold its struggling prey, and sharp anterior teeth to cut up and break the flesh and bones. Thus every animal, whether horse, cow, mouse, cat, or dog, possesses a dentition characteristic of its mode of life, nutrition, and general nature. Since the teeth rub and grind against one another in chewing, they achieve an ideal fit, so that every dentition represents a precision mechanism. It is a kind of tool-kit with a variety of tools that an individual carries around in his mouth for the seizing and cutting up of food.

Man has a "collective" dentition—that is, one where various types of teeth, incisors, canines, premolars, and molars, are represented alongside one another. The teeth are all approximately equal in height and arranged in regular rows. These therefore are the three characteristics of human dentition: simultaneous presence of all four types of teeth, the equal height of all the teeth, and the regularity of their arrangement. The structure of the human teeth proves conclusively that the human body, as regards its anatomical structure, is adapted to a mixed plant and animal diet. This fact may appear distasteful to some, but it cannot be denied.

The Dental Formula. The number and arrangement of the teeth are indicated by the dental formula. The human formula is $\frac{3212|2123}{3212|2123}$, that is, regarded from the mid-line, man has 2 incisors, 1 canine, 2 premolars, and 3 molars in each half of each jaw, making a total of thirty-two permanent teeth. Since all mammalian dentitions are symmetrically arranged, the left half may be disregarded for the sake of convenience, and the formula written as follows: $\frac{2123}{2123}$. In a manner of speaking, 2123 is the

telephone number of the permanent human teeth, while the milk teeth, lacking molars, have the formula $\frac{212}{212}$.

The Wisdom Teeth. Although opinions differ on this subject, a great many people incline to the belief that human teeth are degenerating. Yet whether one accepts or rejects this opinion there can be no doubt that the teeth of present-day

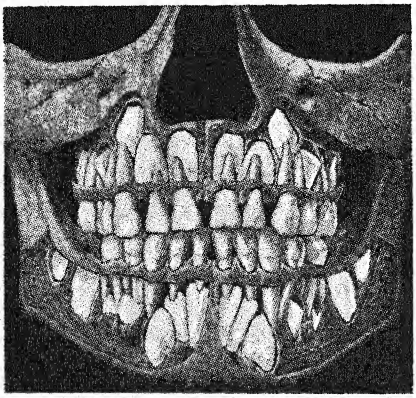


FIG. 84. *The dentition of an eight-year-old child. Beneath the erupted milk teeth lie the permanent teeth. While growing, the latter push the milk teeth ahead of them, and should have replaced them by the age of twelve.*

man show differences from the teeth of ancient man, an indication that human teeth have undergone certain evolutionary changes. One need only look at the two jaws in Figure 78 in order to obtain some idea of the fate of the human teeth in the past 500,000 years. In the first place the number of teeth in man is decreasing. The ancestors of man still had a fourth molar. It is infrequently found in modern man, although among orang-outangs one animal in twenty still has this structure. But even the third molars are disappearing. They appear so late that they have been named the "wisdom teeth," apparently in the belief that their appearance coincides with the age of wisdom. Frequently they remain uncut, causing pressure and pain to such a degree that they must be extracted. Similarly the upper lateral incisors show evidences of degeneration, since they fail to appear in a considerable number of people. In modern man the jaws are also shorter and less prognathous than in prehistoric man, with the result that the teeth are more crowded and less regular in the former.

Dental Diseases. The degeneration of the teeth is the internal cause of dental diseases. In modern man, as has been pointed out, the jaws are shorter and the teeth crowded together. In addition, man injures his teeth by his civilized mode of life.

Caries. The most frequent dental disease is dental decay or caries. A defect appears in the enamel. The bacteria present in the mouth wander into this break in the enamel surface and settle under the enamel. They cannot eat the enamel, but they are situated on the juicy dentine, where they flourish and multiply on the nutritious lymph of the dentine canals. They erode the walls of the canals, thus giving rise to a cavity beneath the enamel. Small defects remain unnoticed, but if the wall of the tooth becomes thin as a result of bacterial activity, heat and cold penetrate more strongly than usual to the pulp cavity and stimulate the nerves present there. If a tooth shows evidence of sensitivity to heat and cold, the condition is to be regarded as an alarm signal. When the bacilli penetrate through the dentine canals into the pulp

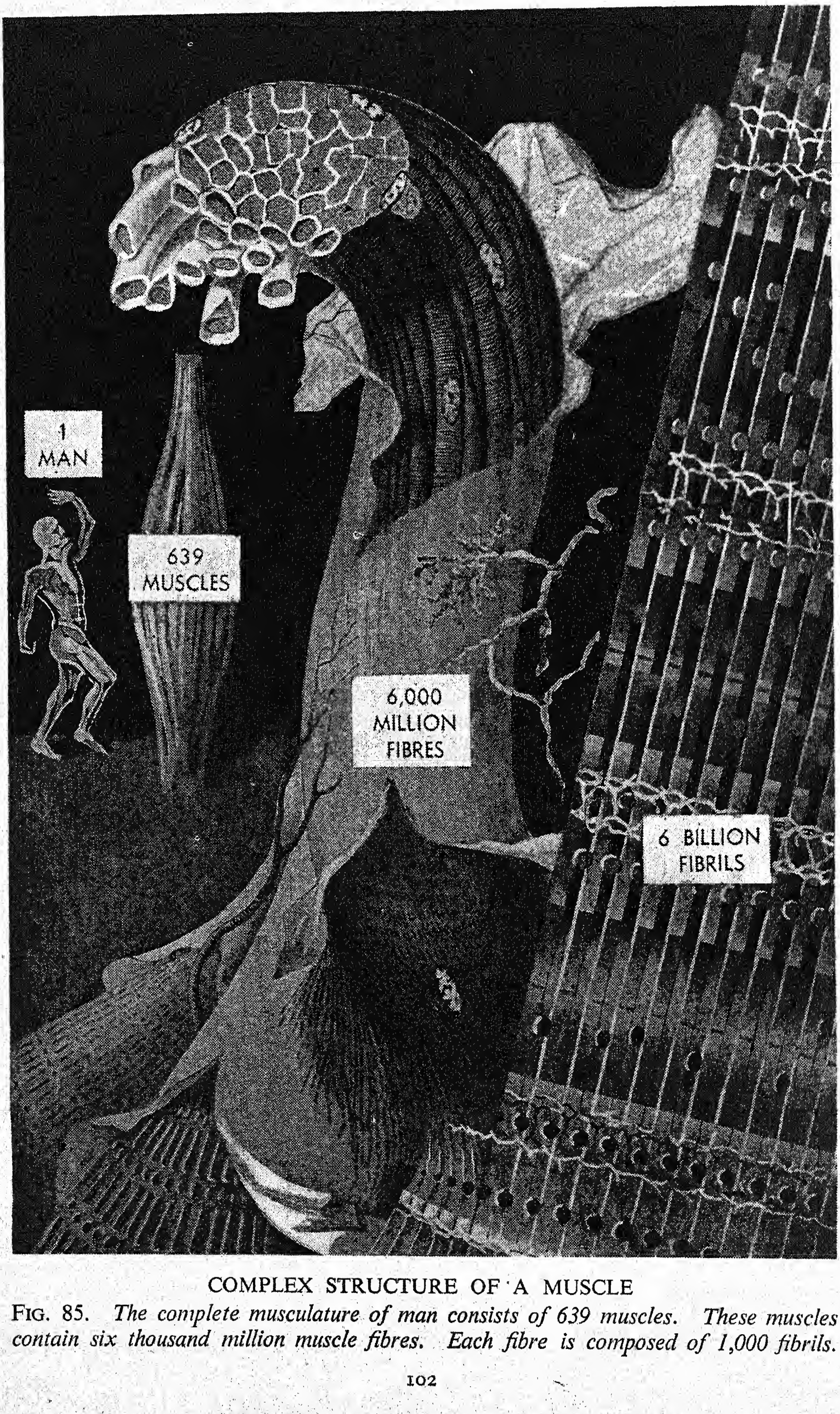
cavity, they find an almost ideal culture medium, a kind of incubator, in the spongy pulp. They feed on the lymph tissue and nerves, and now the tooth begins to ache. Once the process has progressed so far, however, the fate of the tooth is generally sealed. The vascular network withers, the lymph vessels collapse, the microscopic starfishes and polyps die on the walls of the pulp cavity, and with them the long processes of these cells that nourish the dentine. Now the dentine wall is no longer nourished, the vascular heating system is out of order, the lymph-water-supply system is empty, the connective-tissue fibres, as delicate as a spider's web, have fallen apart—the living house has become a ruin. The tooth is dead.

Healthy Teeth

A normal healthy tooth with a pulp is a living organ traversed by blood and lymph vessels, nerves, and cellular processes. The more it is used, the healthier it is. A tooth where the pulp is diseased to such an extent that the dentist must eradicate it is a dead shell. It still stands in its socket, but it is no longer alive. A healthy tooth with a live root bears the same relationship to a tooth with a dead pulp as a tree in a forest to a mast on the deck of a ship. Anyone who wants to retain his teeth as living organs should have them examined regularly and have any damage repaired before the appearance of pain, so as to postpone the death of the tooth as long as possible.

Irregular Teeth

As a consequence of the development of the jaws in modern man, the teeth in many cases no longer have enough room. They erupt in a crooked position or become shifted from their normal position during the growth period. If a tooth in the lower jaw occupies an anomalous position, the opposing tooth in the upper jaw likewise assumes a crooked position. Slight deviations from the normal remain unnoticed, but marked displacements mar the mouth. The teeth project beyond the lips, the lips are pushed outward, the chin recedes, the upper lip is elevated towards the nose, and so on. Parents who want to make the path which their child will traverse in life as smooth as possible and to remove all possible obstacles should pay attention to the condition of the child's teeth, and train him to clean them regularly and treat them with care.



COMPLEX STRUCTURE OF A MUSCLE

FIG. 85. *The complete musculature of man consists of 639 muscles. These muscles contain six thousand million muscle fibres. Each fibre is composed of 1,000 fibrils.*

III: THE MUSCULATURE

CHAPTER VIII

Muscle Structure and Function

SMOOTH MUSCLE FIBRE. MUSCLES OF THE CIRCULATORY SYSTEM. MUSCLES OF THE RESPIRATORY PASSAGES AND THE ŒSOPHAGUS. STRIATED MUSCLE FIBRE. VOLUNTARY AND INVOLUNTARY MOVEMENTS. FATIGUE—LACTIC-ACID POISONING. MUSCLE TWITCH AND TONE. TONUS. MUSCLE SENSE. TRAINING. TENDONS. THE MUSCLE MACHINE.

ALL connective-tissue cells have the ability to contract. In some parts of the body the connective-tissue cells develop this ability to a special degree and thus transform themselves into muscle cells. In its primitive form a muscle cell is spindle-shaped and is known as a smooth muscle fibre. In order not to be abraded by its environment when in motion, the fibre secretes a delicate membranous sheath and now resembles an acrobat in tights. At those points where the muscle cells are frequently employed they multiply and become organized. The small cellular acrobats clasp hands, unite their sheaths, and become a single smooth muscle composed of many fibres [Fig. 86].

Gooseflesh. The simplest type of smooth muscle is the muscle attached to the shaft of a hair [Fig. 87 (a)]. Hairs do not stand upright in the skin like trees, but lie at a slant like wheat after a rain (b). At the base of each hair is a sebaceous gland. Its function is to grease the hair so that it will remain supple. Beneath this gland is the attachment of a bundle of smooth muscle fibres. This muscle arises in the superficial layer of the skin and is attached to the hair shaft on the side towards which the hair slopes. When the muscle contracts, it diminishes the obliquity of the hair insertion and elevates the hair.

The sebaceous gland is placed in the angle which the muscle forms with the hair, so that the contraction of the muscle squeezes the sebaceous secretion out of the gland (c). These hair muscles are highly developed and active in animals because they are important for wild animals. If an animal begins to feel cold or is threatened by enemies, the muscles contract and ruffle up the animal's fur or its plumage. This mechanism gives the animal four advantages. In the first place, the ruffled fur keeps the animal warmer because it creates a thick, resting layer of air which surrounds the body, thus retaining the body temperature, since air is a poor conductor of heat. Secondly,

the contracted muscles evacuate the sebaceous glands and grease the skin; this is the best possible protection against cold. Thirdly, because of its ruffled pelt the animal appears larger and more dangerous to its enemies; and fourthly, the erect hairs pad its body and protect it against blows and bites. In man this mech-

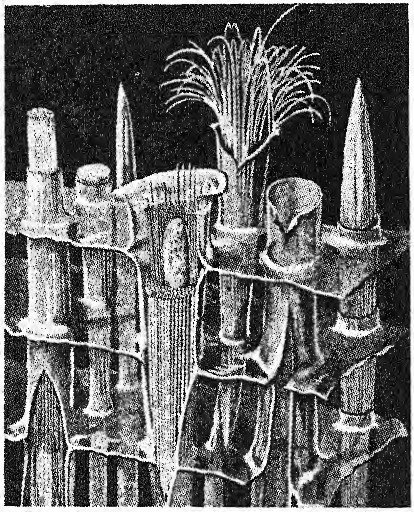


FIG. 86. *Smooth muscle fibres. The smooth muscle fibres are covered by connective-tissue sheaths and formed into linked functional units by means of interconnecting fibrous tissue.*

anism has degenerated together with his coat of hair, and functions only occasionally under strong stimuli. If an individual is badly frightened or very angry, or if a cold draught passes over his warm body, the hair muscles contract, the hairs stand on end, and the sebaceous glands appear prominently under the surface of the skin as in a goose. For this reason this condition is called "gooseflesh" [Fig. 87]. The small skin vessels that supply the skin with warm blood likewise contract, the skin becomes cold, and the individual becomes conscious of this state as a shiver.

The Pupils. Around circular body orifices such as the pupil of the eye smooth muscles form flat rings [Fig. 88 (b)]. Stand in front of a dimly illuminated mirror and examine your eyes. The pupils are dilated (I, b). If a light is now flashed in your eyes, the smooth muscle fibres contract and narrow the pupils to protect the retina of the eye, which is sensitive to light (II, b). This play of the pupils, which is continually taking place so as to adapt the eyes to changing intensities of light, can best be observed in cats.

The Muscles of the Circulatory System and Hypertension. All the vascular tubes of the body are encompassed by smooth muscle fibres arranged circularly around the vessel. Even when they are not active they are always in a certain state of tension, called tonus. The calibre of the vessel is determined by the degree of tonus. Wherever blood is needed, the fibres relax and the vessels dilate; wherever organs are at rest and require little blood, the fibres decrease the calibre of the vessels, thus restricting the flow of blood in the particular area. As an example we may cite the blanching and blushing of the face. If the muscle fibres of the blood vessels underlying the skin of the face relax, the vessels dilate and the individual blushes (I, c); if the muscles contract, the vessels are narrowed and the face becomes pale (II, c).

Chronic spasm of the vascular muscles is not the only cause of high blood-pressure (hypertension), but it is not infrequent (II, e). If such spastic attacks occur in the walls of blood vessels, they give rise to "crises" in the area supplied by the affected vessels. Spasm of the cerebral arteries

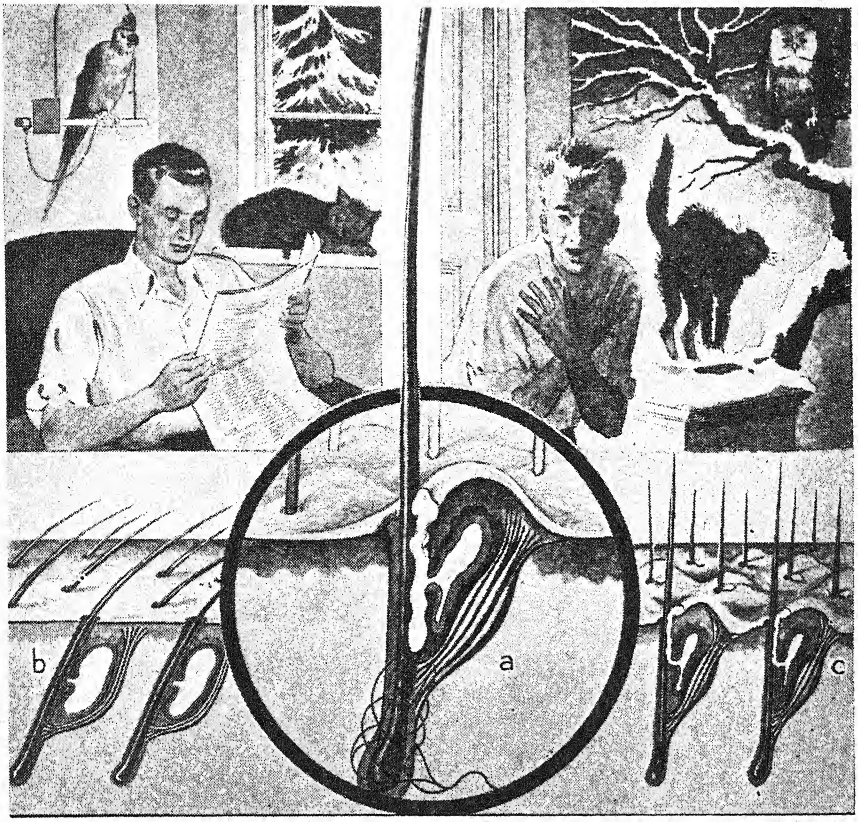


FIG. 87. *How a shiver is caused in man, mammals and birds. At (a) is shown a hair shaft and its mechanism. When the body is warm and at rest, the hair muscles are relaxed and the hairs are inclined at an angle to the surface of the skin (b). But if the body becomes cold or excited, the muscles contract and the hairs stand erect (c).*

causes fainting spells (II, a), and spasm of the coronary arteries of the heart produces attacks of angina pectoris (II, g).

The Muscles of the Respiratory Passages and Asthma. The circular fibres that surround the respiratory passages regulate the calibre of the respiratory canal and the supply of air for respiration. If the fibres are relaxed we feel at ease and breathe freely (I, f). Asthmatic attacks are caused by sudden contractions of the muscle rings in the respiratory passages. In an asthma attack the respiratory passages become narrowed to such a degree that the individual cannot inspire or expire a sufficient quantity of air despite the utmost efforts of his ribs and diaphragm (II, f.).

The Muscles of the Œsophagus. Generally the circular muscle fibres are covered by an external layer of longitudinal fibres parallel to the long axis of the organ. These double layers are particularly well developed in the walls of the stomach and the

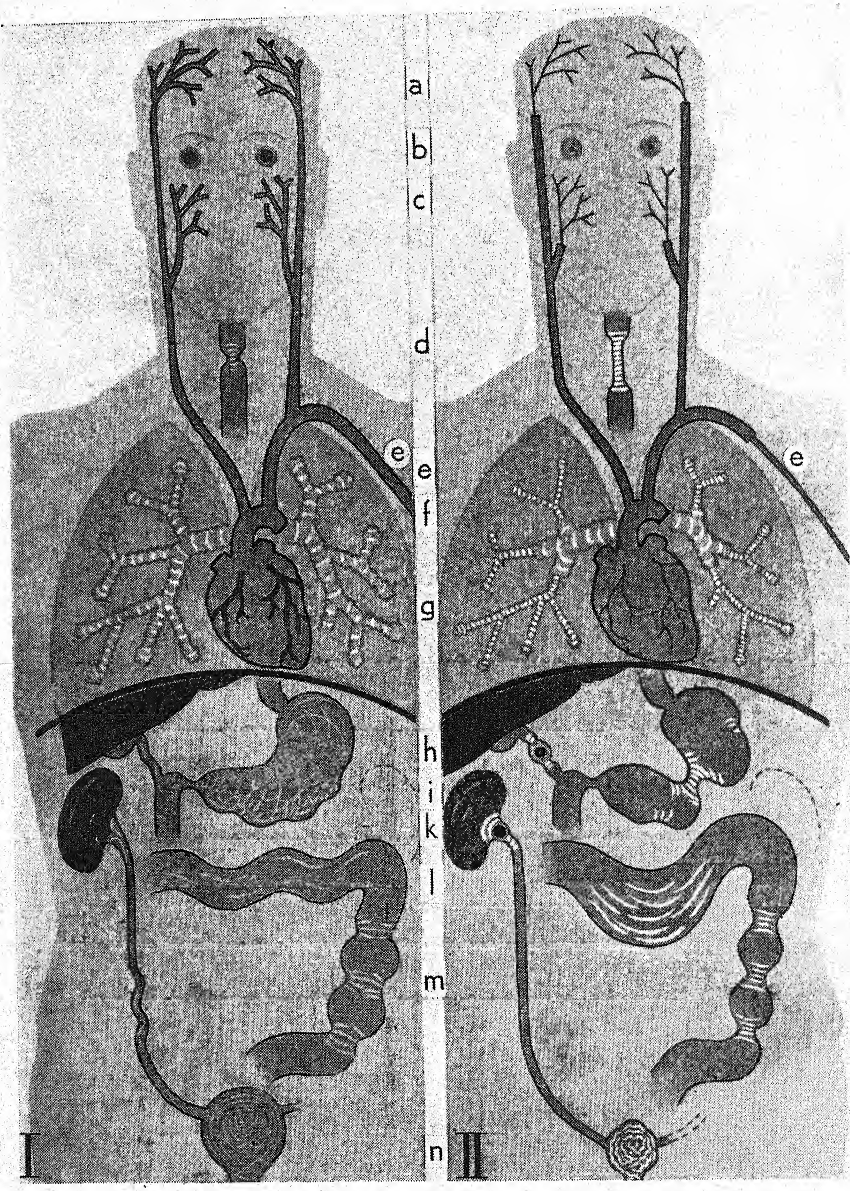


FIG. 88. *The smooth musculature of the human body when functioning normally (I). At (II) are shown the smooth muscles under various spastic and pathological conditions. These are: (a) anæmia of the brain (fainting); (b) contraction of the pupils; (c) paling; (d) œsophageal spasm; (e) vascular spasm (hypertension); (f) bronchial spasm (asthma); (g) spasm of the cardiac vessels (angina pectoris); (h) gall-bladder colic; (i) gastric spasm; (k) renal colic; (l) intestinal atony; (m) intestinal spasm, (n) bladder spasm. Smooth muscle is strong, but functions with comparative slowness.*

intestine. The circular fibres narrow the tube without moving it (d, m). The longitudinal fibres, however, pull the tube to one side wherever they contract, thus producing peristalsis of the tube (i, l). Put an earthworm on a table and watch its movements. Its body is encompassed by circular and longitudinal muscle fibres just like the human intestine. If the circular muscles contract, the worm becomes thinner; by means of the longitudinal fibres it carries out winding movements. The movements of the intestines within our body are like those of the earthworm (l, m).

Intestinal Inertia. Normally the muscle fibres of the intestinal wall are stimulated by the ingested food and the digestive juices. If they prove to be rather insensitive, the intestine is in a flaccid state and functions sluggishly—constipation as a result of intestinal inertia (II, l). Conversely, if the muscles are hypersensitive so that they contract spastically under the stimulation of the food and do not recover soon enough from the spasm, constipation due to intestinal spasm results (II, m). For the sufferer the result is the same in both cases; he has no evacuation.

Difficulties in Diagnosis

The doctor, however, is dealing with two entirely different disease complexes requiring antithetical methods of treatment. This is one of the many cases where one and the same pathological condition can be produced by different—indeed, often by antithetical—causes. If an automobile stalls, the driver knows that the trouble can be due to various causes. The car may be out of petrol, the feed-pipe may be stopped up, the spark-plugs dirty, or the carburettor out of order. No driver is so stupid when his motor breaks down as to make a diagnosis immediately or to undertake any steps to remedy the situation without investigating. He knows that it is absolutely senseless to take the carburettor apart when the petrol tank is empty, or to fill the tank with petrol when the spark-plugs are dirty. As far as the much more complicated "man motor" is concerned, the majority of people assume the naïve attitude that a cause as well as a "cure" can immediately be given for every breakdown without much reflection or investigation!

Muscles of the Organs

Colic. Besides the blood vessels, respiratory passages, and intestine, various other tubular structures of the human body have layers of circular and longitudinal muscle fibres in their walls. Among these tubes is the bile duct, along which the bile passes from the liver into the intestine (h), and the ureter, which conducts the urine from the kidney to the bladder (k). Within these tubes sometimes stones are formed. If such a stone irritates the wall, the fibres contract spastically, and a painful muscle spasm known as a colic is the result. When this condition is present in the gall-bladder or the biliary passages, we speak of a gall-bladder or biliary colic (II, h); when in the kidney pelvis, of a renal colic (II, k).

Hollow Organs. The human body has several cup-shaped hollow organs. In the walls of these organs the original circular and longitudinal fibres have combined to form an exceedingly intricate interlacement, which is arranged in a very efficient and æsthetically beautiful

manner. The three largest organs of this type are the heart, the urinary bladder, and the uterus. Fig. 116 shows the fibre bands of the heart. The largest and strongest muscular organ of this type in the body is the uterus since it must perform the most difficult of all bodily functions: namely, the expulsion of the child from the mother's body. The rhythmic contractions of the uterus during parturition are called labour pains.

The Striated Muscle Fibre. The smooth muscle fibre has great advantages. It is strong. No other muscle in the body is as strong as that of the uterus, which pushes the child through the narrow pelvis. It has great powers of endurance.

Slow and Rapid Motion

Many of the smooth muscles act like good spiral springs; they can exist in a state of tension uninterruptedly for decades. This is true, for instance, of the muscle fibres of the pupil, which never relax completely during life, as well as of the sphincters of the bladder and the stomach. Smooth muscle, however, functions slowly. Watch an earthworm and see how slowly it crawls; this is the type of movement characteristic of smooth muscle. Compare the sluggish movements of the earthworm with the lightning speed of a fly buzzing through the air. Observe an abdominal cramp and see with what relative slowness it passes along the intestine; then compare it with the rapidity with which we blink our eyes. Wherever rapid motion is required, the smooth muscle fibres have developed into a higher form which in contrast to smooth muscle is called striated. The entire skeletal musculature by means of which we move our limbs belongs to this striated type of muscular tissue.

Man has 639 muscles, each named according to a list drawn up by international agreement [Fig. 85]. In their totality the muscles make up the flesh of the body. The red meat bought at the butcher's is muscle.

Fibres and Fibrils

Muscles are found in the most varied shapes. The normal form is that of a spindle, and because of its resemblance to a swiftly running mouse it was named *musculus*, or "little mouse." A medium-sized muscle contains approximately ten million muscle cells. About six thousand million muscle cells are contained in the total musculature. In the centre of Figure 85 we see a highly magnified muscle cell, or fibre. It is composed of bundles of still more delicate fibres, called fibrils. The 639 muscles of the body contain in all six billion fibrils.

The outside of the cell is covered by a sheath, beneath which lie numerous cell nuclei, for a single nucleus could not possibly control the entire cell. Blood vessels and nerves approach the fibre from the exterior (centre of the picture).

The Fibril Motors

If the fibrils are examined with a microscope under magnifications of a thousand times or more, it can be seen that each one is composed of a system of light and dark boxes between which small spheres and networks are distributed at regular intervals (at right of illustration). These systems are the active elements of muscle movement, the motors of the human body. They effect the contraction of the muscle by altering the degree of swelling of each system. This is accomplished by transferring

the fluid content of each tiny box to its neighbour. Each fibril "motor" consists of ten boxes arranged one behind another, and in the 639 muscles of the human body there are no less than six thousand million such ten-cylinder "motors."

Muscle Fibre and Automobile Motor. In the performance of its work the fibril "motor" of the muscle fibre actually exhibits surprising analogies to an automobile motor. The chief points of resemblance are displayed in Figure 90, where the numerals relate to the following paragraph numbers:

1. Both automobile motor and muscle fibre are combustion engines

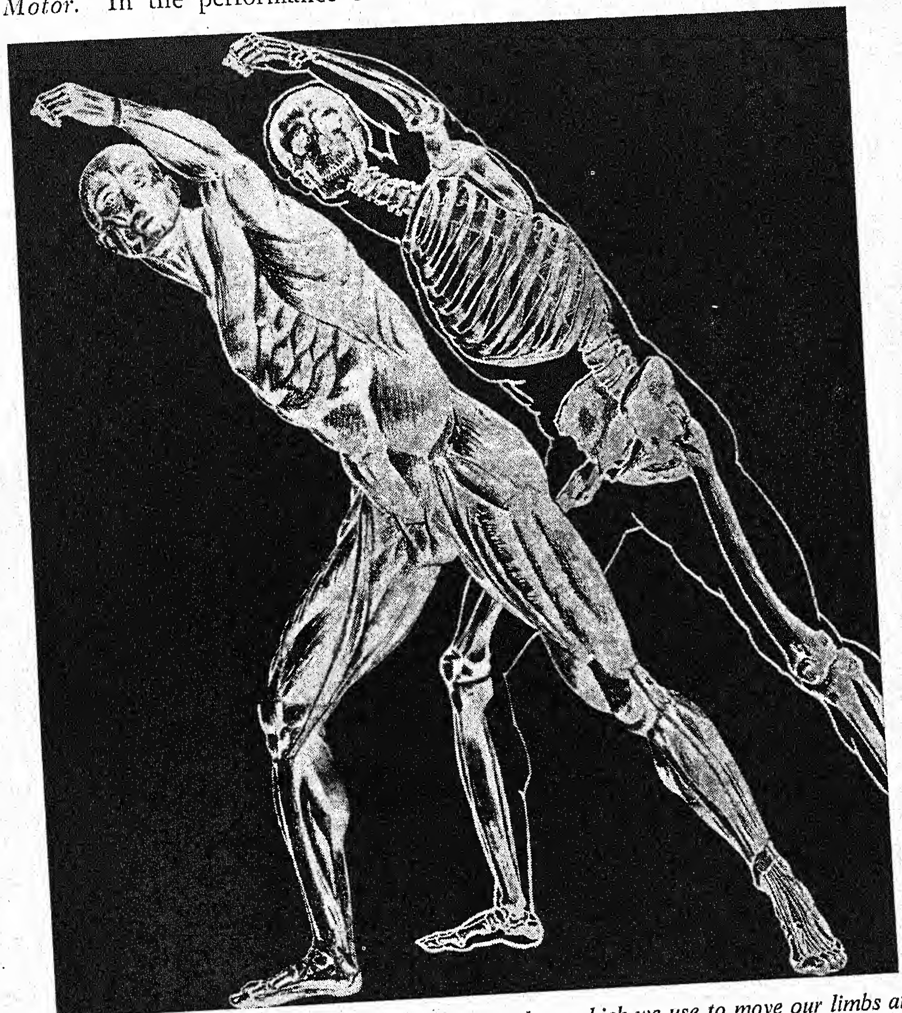


FIG. 89. *The striped, or striated, muscles are those which we use to move our limbs at the dictate of the brain. Accordingly they are situated in the outer part of the body, between the bones, in contrast to the slow-acting smooth muscles of the organs and viscera, which are located more deeply, in the interior of the body.*

in which a high-grade fluid fuel is consumed to carbon dioxide and water.

2. In an automobile as in a muscle the fuel is supplied to the motor from a tank; in the human body the stomach and the gastro-intestinal canal perform this function.

3. In both cases fuel is supplied by means of a pump; in the human body this function is performed by the heart.

4. In the automobile motor as well as in the muscle fibre oxygen is required for the combustion of the fuel. For this reason each has a carburettor; in the human body the lungs might be looked upon as the analogue of the carburettor.

5. After the fuel has been mixed with oxygen it is carried to the motor by a feed-pipe; the feed-line of the human body is the artery.

6. The functioning elements of the muscle "motor," the fibril boxes, are arranged in rows like the cylinders of a car.

7. In the automobile motor as well as in the muscle fibre the combustion of the fuel in the cylinders is produced by an electrical impulse. In the automobile the current is furnished by the ignition, in the human body by the nervous system.

"Spark-plugs" of the Body

8. In both the motor and the muscle fibre the current is conducted by wires that end in special apparatuses in the cylinders. In the automobile motor they are known as spark-plugs; in the human body their analogues are the motor end-plates.

9. After the combustion of the fuel to gaseous carbon dioxide and water, these end products are carried off as exhaust gases through tubes, which are called veins in the body.

10. In an automobile, as in the human body, the motion of the motor cylinders is transmitted to rotary joints which move the wheels of a car, or the limbs of the human body.

11. In an automobile as in the human body the rotary joints are kept functioning smoothly by means of automatic lubrication.

Points of Difference

The points of correspondence between the muscle fibre and the automobile are striking. Despite the similarities, however, the differences should not be overlooked. An automobile motor is a machine in which a vaporized fuel is caused to explode, and the explosive force is transmitted to pistons and shafts. The muscle is a protoplasmatic motor, the structure of which is still unknown to us at present. Instead of pistons and cylinders it works with protoplasmatic boxes filled with semi-fluid contents. These boxes contract under the electrical impulses of the brain, in that the semi-fluid protoplasm congeals for a fraction of a second and becomes fluid again. This process is accompanied by a polyphasal chemical reaction. During this process the glycogen molecule is broken down into glucose, which combines with phosphoric acid. This compound is then divided into three lactic-acid molecules, of which one is used for fuel, while the other two are resynthesized into glucose. The elucidation of this process is a triumph of modern science, and the scientists who accomplished this have been awarded a Nobel prize. However, the nature of the protoplasmatic motor itself is still a mystery.

The Arrow Poison, Curare. An automobile motor runs only if the

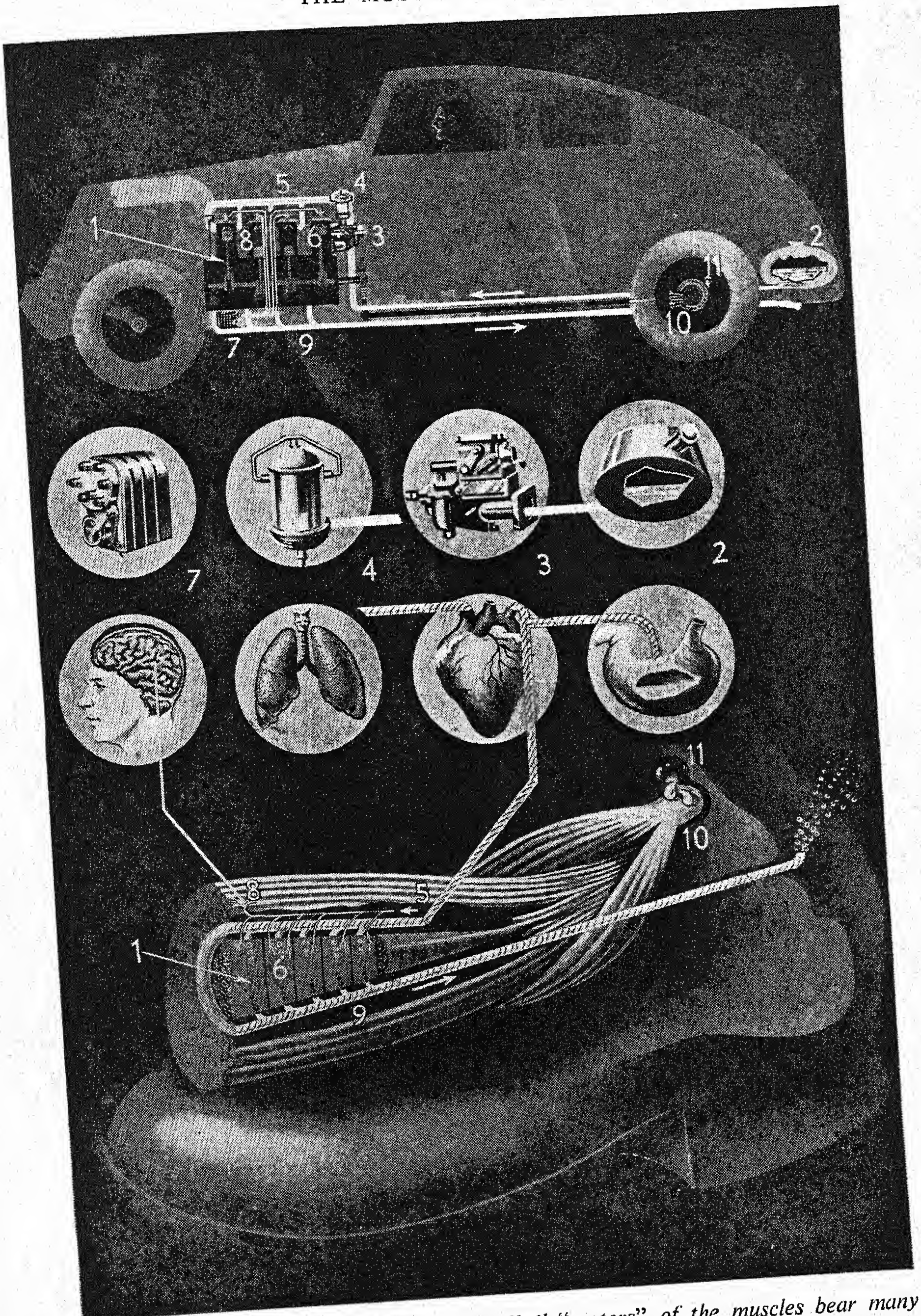


FIG. 90. *In their mode of operation the fibril "motors" of the muscles bear many striking points of resemblance to the mechanism of a motor-car engine. (Pages 109-110).*

ignition spark causes the petrol vapour to explode. Similarly the muscle motor in the body can contract only if the nervous system furnishes igniting nerve impulses. The muscle fibres are connected by means of conducting wires, the nerves, with the nervous system, from which they receive their contraction stimuli. It can be estimated that in the human body several million nerve "wires," used entirely as ignition leads, run between the brain and the muscles, where they split up into thousands of millions of end connections. Each lead ends in the muscle fibre with a broad electrode, the motor end-plate [Fig. 85, *centre of the picture*]. The Indians of Guiana smear the tips of their arrows with a poison called curare. This arrow poison has the property of paralysing the motor end-plates; in terms of automobile mechanics one might compare the curarized end-plates to carbonized spark-plugs. After the elimination of the "spark-plug" the fibre can no longer contract, and the muscle is paralysed. The arrow poison causes no pain, and at first the victim notices no ill effects while the poison is carried by the blood from the wound throughout the entire body. But one after another various groups of muscles become paralysed. If the victim has been struck in the arm, it is the first limb that he can no longer move; then his legs become heavy, he sits down, and falls to one side. He wants to bend ~~his legs, but cannot. He wants~~ to close his eyes, but he can no longer move his lids; he wants to scream, but his tongue lies leaden in his mouth—he has been cruelly paralysed. The victim hears and sees everything. He feels the pains caused by the drying of his eyes and mouth, by his unchanged position on the hard ground, but he cannot defend himself. A creature that has been curarized can be cut to pieces, its

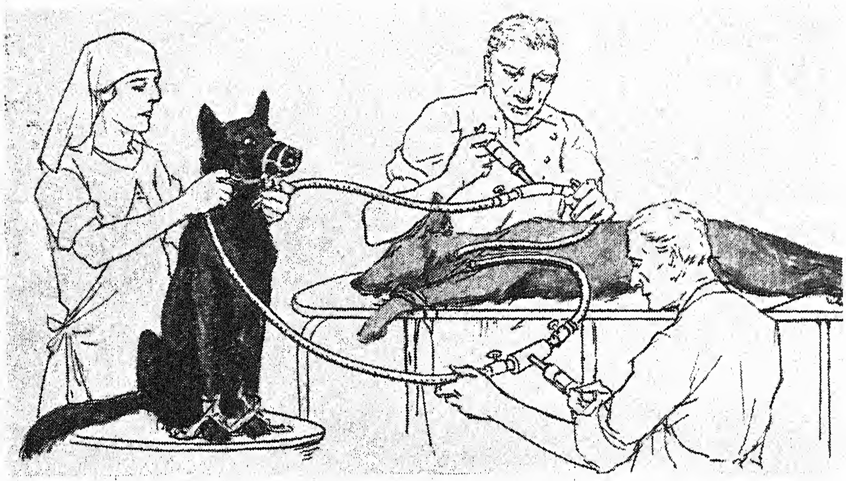


FIG. 91. *Here a grey dog, which is fatigued, and a black dog, which is quite fresh, are having their blood interchanged. As the blood of the grey dog, laden with waste products of fatigue, enters the body of the black dog, the latter becomes drowsy (Fig. 92).*

chest can be opened and the heart action observed, yet it cannot make the slightest movement to defend itself—curare is the cruellest of all poisons. Finally the respiratory muscles are paralysed, respiration grows more difficult, and the miserable victim dies without uttering a sound.

Voluntary and Involuntary Movements. The brain as a whole does not function as an ignition machine, but only a certain cerebral convolution called the motor centre. This is connected with the centre of volition, and because of this fact we can move our muscles as we desire. But only the striated fibres of the skeletal musculature, of which the external layer is represented in Figure 89, are connected with this motor centre in the brain. The smooth fibres of the viscera that are historically older are under the control of the historically older and lower nervous system within the abdomen, the sympathetic, and have no relation to the spheres of volition or consciousness. We can move our arms as we desire, but we cannot dilate or contract our pupils or become pale at will. Take a mouthful of water. As long as the water is in the mouth, in the sphere of the striated muscles of the tongue and the cheeks, we can swallow it or spit it out. But as soon as it has passed the pharynx into the sphere of the smooth fibres of the œsophagus, it is beyond the influence of our will. The striated skeletal musculature is voluntarily movable; the smooth visceral musculature functions automatically, and independently of our will.

Fatigue — Lactic-Acid Poisoning. The lactic acid produced by a contracting muscle is a fatigue poison and the chief cause of fatigue. If the lactic acid is removed from a tired muscle, its ability to work returns. In the course of a day we poison ourselves with lactic acid. In addition there are still other fatigue-producing substances, especially products arising from the destruction of protoplasm, so-called fatigue toxins. They arise during muscular activity and

FIG. 92. *The black dog (Fig. 91) has fallen asleep, while the grey dog is now wide awake—its blood free from toxins.*

are carried by the blood through the body, thus producing fatigue, not only of the muscle itself, but of the entire body, especially the brain. In addition to the local fatigue of the working muscle, muscular labour leads to a general fatigued condition of all the organs and central fatigue of the brain. Fatigue is a kind of blood-poisoning by means of lactic acid and toxins. If a dog is made to work until it is exhausted and falls asleep, and its blood is then transfused into the body of a fresh animal [Fig. 91], the latter tires and falls asleep during the transfusion. Conversely, if blood from a wide-awake dog is transfused into a sleeping

animal, the latter wakes up [Fig. 92]. Similarly, an exhausted human being can be restored to full working efficiency immediately through the administration of fresh blood or the serum of a rested body. Yet one should not believe that we thus have a magic remedy at hand, and that in the future man will be able with the aid of a fatigue anti-toxin to get along without sleep, and work or amuse himself twenty hours daily. Fatigue, like every change in the body, is not only a chemical but also a biological process. Elimination of fatigue means not only that the wastes of the body must be removed but also that the cells need rest. They must recuperate, damages must be repaired, the nerve cells of the brain must recharge their batteries, the joints must replace the used-up supplies of joint lubricant. After every day's trip the body of the human "automobile" must be thoroughly cleaned, lubricated, and refuelled.

Overcoming Fatigue

Herein lies the mystery of this "car" that can continue to run for, say, eighty years. There is no danger that science will rob man of the pleasure of sleeping. A fatigue anti-toxin will be an excellent help in overcoming fatigue when great exertions are required. When we are tired, however, we ordinary people will sleep off our lactic-acid intoxication in the good old way.

Exhaustion. Someone is in the midst of strenuous athletic activities. Suddenly he can no longer breathe, his strength fails him, he appears ready to collapse. He can no longer carry on and would simply like to fall down and go to sleep on the spot. This is exhaustion. The exact cause is unknown, but we do know that it is a transient kind of paralysis. Whether it is produced by an excess of lactic acid or carbon dioxide or other fatigue-producing substances is still undecided.

The Second Wind. Every experienced athlete knows that to a certain degree fatigue can be overcome by mustering the necessary energy. The body then feels as if newly liberated; the individual breathes more easily and accomplishes twice as much.

Value of Training

This is "second wind." An untrained person succumbs to fatigue; someone who is trained overcomes it and uses his second wind to achieve victory. It is one of the aims of good athletic training to teach young athletes to be able to overcome fatigue and to understand how to employ their second wind to best advantage.

Rigor Mortis. Several hours after death the muscles swell, become shorter, and stiffen. This state is known as rigor mortis. A slaughtered chicken becomes so stiff that the wings can hardly be lifted from the body. Rigor mortis begins at the jaws and passes downward over the neck and trunk to the limbs. After ten to eighteen hours it vanishes in the same order. The greater the state of exhaustion of the muscles has been, the more rapidly does it set in.

The Law of Time. The body is not a machine. It is more than that. It lives according to laws that have no validity for machines. The concept of times does not exist for a machine. It is immaterial whether the petrol tank of an automobile is filled at six in the morning or ten at night. For a living organism, however, the time of any act is by no means a matter of indifference.

A bottle of wine is a bottle of wine, no matter whether it is in a store or in a wine cellar. For the human body, however, it makes quite a difference whether a bottle of wine is drunk at eight o'clock in the morning on an empty stomach or enjoyed in the evening before going to bed. It makes quite a difference whether the bottle is emptied in one swallow or whether it is finished slowly in the course of an hour. A hot bath before a meal has quite a different effect from one after a meal. The action of massage also is quite different for a rested individual and for a tired one. After strenuous muscular activity massage has a refreshing effect because the fatigue toxins are excreted from the muscles, blood, and skin glands. Conversely, if the body is rested and the blood free of fatigue poisons, massage acts in a contrary manner. The "fatigue remains" are squeezed out of the muscles, pass into the blood and the brain, and produce a pleasant feeling of lassitude, a mild state of intoxication.

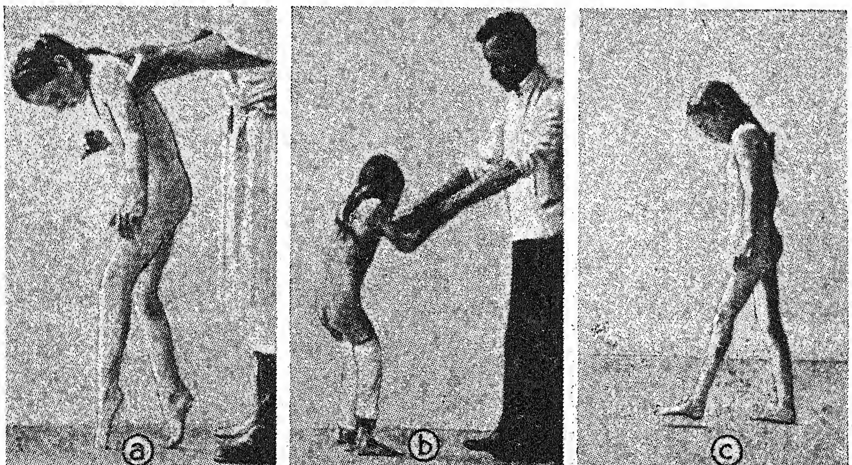


FIG. 93. *(a) Abnormally increased tonus leads to spastic contraction and inability to walk; (b) three hours after severing some of the nerves the girl can stand; (c) two weeks later she is able to walk normally, because her natural muscle tonus has been restored.*

Rest by Means of Activity. What does a person do who has been sitting at his desk for many hours and is tired? Does he lie down? No! He takes a walk. What do children do when they come home from school and are tired? Do they go to sleep? No! They run to the playground. If the body is completely exhausted by strenuous labour, a long hike, a washing-day, or a moving-day, one recuperates best by lying down and permitting the organism to rest. However, if only a certain part of the body is tired—for instance, the brain by long calculations, the hands from many hours of typing, the eyes by too much reading or sewing, or the legs when one has had to stand very long—the tired limb or organ recuperates best if other rested parts of the body are active. If one lies down, all the activities of the body are curtailed; in a manner of speaking, the vital furnace of the body is

banked. The heart beats slowly, the blood vessels contract, respiration becomes shallow, and the exhausted brain sleeps, so that all the organs are at rest. On the other hand, if one enters into some new activity—if after a long lecture one goes out into the fresh air, thus exposing oneself to new impressions and stimuli,

FIG. 94. *When the muscle tonus is decreased by disease, the limbs lose their tension and become loose and flaccid.*

to the cool air and the fragrance of flowerbeds—respiration is increased, the blood circulates faster, and the glands are more active, thus facilitating the elimination of waste products from the exhausted organs. If you are totally exhausted, go to sleep! If only part of your body is tired, go for a walk, or take a swim, play chess or cards, engage in athletics, or occupy yourself with your stamp collection or your garden! There is no better form of rest for an exhausted organ than the activity of neighbouring organs.

Muscle Twitch and Muscle Tone. When a muscle is stimulated either mechanically by pinching, or chemically by means of an acid, or by an electrical current, it shortens rapidly. The entire phenomenon is known as a simple muscular contraction or a muscle twitch. The duration of such a twitch varies for different animals. The muscle twitch of a sluggish turtle takes one second, while that of a frog lasts one tenth of a second. If a muscle is stimulated repeatedly at short intervals of less than one tenth of a second before it has time to relax, it will respond to the successive stimuli with contractions that become fused. Such a series of fused contractions is known as a physiological tetanus.

This physiological tetanic contraction of a muscle is not a static condition, as it may appear to us, but consists in a summation of individual contractions, just as an image on a motion-picture screen, even when it is apparently not moving, is not a permanent picture, but is composed of a number of individual pictures following one another in rapid succession, or just as the even light of an electric bulb supplied by an alternating current really consists of a large number of separate impulses per second. Under normal conditions the muscles of the human body contract in response to stimuli from the motor centre of the brain. When the nerve cells discharge their impulses into muscles the discharge is never single, but always a series of impulses in rapid succession. In consequence voluntary muscular contraction is tetanic in character.

The internal discontinuity of activity during tetanus finds its expression in the so-called muscle tone. If a stethoscope be applied to a contracted biceps muscle, a dull noise can be heard. This is the muscle

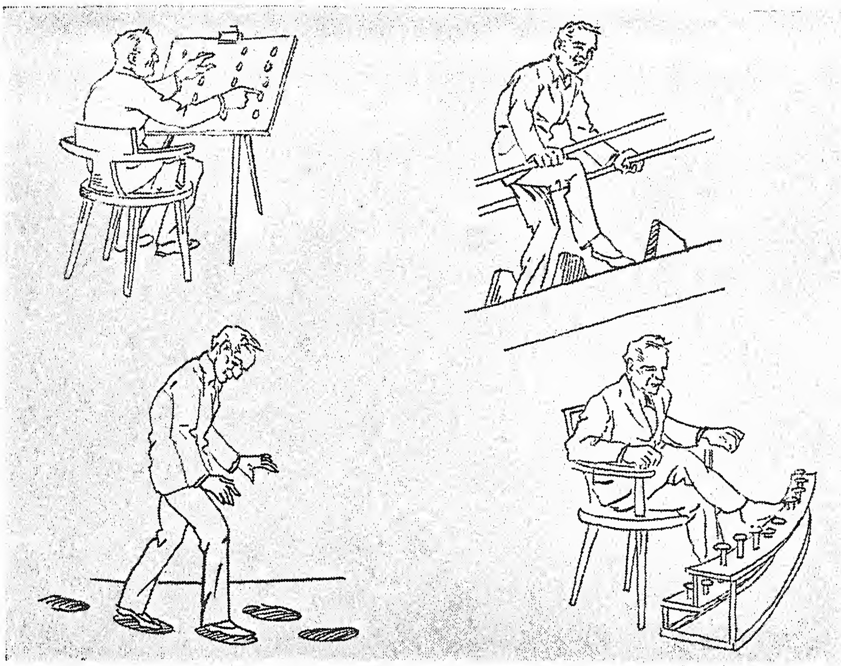


FIG. 95. *With the aid of therapeutic exercises similar to those shown above, a patient whose muscle sense has disappeared can be taught to regulate the movements of his limbs by means of visual control, and eventually regains the power to walk unaided.*

tone. Every one of us has heard our own muscle tones at some time, even though we may not have paid any attention to them. When we yawn, we can hear the muscle tone of the head musculature; or if the external auditory canals are closed by placing a fingertip in each ear, and the jaw muscles tensed by pressing the teeth together tightly, the roaring tone of the jaw musculature can be heard very distinctly. The muscle tone is probably due to a vibration of the muscle produced by the discontinuous excitation.

Learn to Relax! These experiments teach us an important fact: a contracted muscle is a working muscle! A contracted muscle uses up nervous energy, consumes sugar, produces lactic acid, and creates fatigue. In order to rest one's muscles and to protect the body against any increase of fatigue substances so as to let the brain really rest, the muscles must be relaxed.

Tonus. A certain degree of sustained muscular contraction is natural and is known as tonus. In the brain there is a centre, the "red nucleus," which sends impulses to the muscles maintaining them in this state of mild, sustained contraction. A violin string offers the best example for an elucidation of the concept of tonus. A correctly tuned violin string is in a state of normal tonus. If it is too tightly stretched, its tonus is increased; if it is loose, the tonus is diminished. The stalk

and leaves of a healthy plant maintain their position because, owing to their water content, they possess a certain degree of tonus. If the plant suffers from a lack of water, its tonus is diminished and it becomes limp. Similarly a living body, as contrasted with a dead one, is in a like state of swelling and tension. During life the muscles are never completely relaxed. Let us imagine that the tension of muscle is being measured by means of a manometer graduated from 0 to 100. On this scale the tension of a relaxed muscle is not 0 degrees, but about 10 degrees.

"Clock Spring" Muscles

In some ways a muscle resembles a spring in a clock. Even when it is run down, the spring is not completely relaxed. Similarly, an arm when at rest does not hang loosely but is somewhat bent owing to the tonus of its muscles. In a live person the arms are shorter than in a corpse. If the muscles of an arm lose their tonus owing to nerve paralysis, the arm hangs limply and becomes longer. In the matter of tonus a muscle resembles a runner, crouched at the starting-line and waiting with tensed muscles for the sound of the starter's gun. Owing to their tonus, all the muscles of the body are ready to start, and when the signal to start comes from the brain in the form of a nerve impulse, they lose no time, just as a violinist can play immediately if the strings of his instrument are correctly tuned. Owing to the sustained tonic contraction of the muscles, an individual saves approximately one fifth of his time and energy. If our muscles were not in a state of tonus, the energy required for any task would be one fifth greater. Instead of eight hours we should have to work more than nine hours to perform the same quantity of labour.

Tonus is not a fixed and permanent condition, but is subject to variations. If the tonus in any muscle were to be registered with the aid of a manometer, we should see the instrument oscillating back and forth like the magnetic needle of a compass. A rested and healthy body has an increased tonus. To verify this statement one need only observe hikers setting out on a trip and then see the same people returning home tired and weary in the evening. Their tonus has decreased. The people have become smaller, they are more round-shouldered, and their heads tend to fall forward because the sustained tension of the neck muscles is diminished. This change of tonus is best observed in the face. The skin of a healthy, refreshed individual is taut. When the individual becomes tired, the tonus of the muscles is decreased, folds appear in the skin, and the face presents an appearance of weariness. We generally tell someone in this condition: "You look tired"; but we could just as well say: "Your tonus is diminished."

Abnormal Tonus

During a faint, blood circulation in the brain is disturbed, with the result that the stream of nervous impulses that maintain a normal tonus is interrupted and the individual collapses. There are diseases, particularly of the brain or nerves, which diminish tonus, and others which increase it. The child in Figure 93 is suffering from an increase of muscle tonus. It cannot walk because the tonus of its leg muscles is so great that all the muscles are spastically contracted (a). To decrease the ex-

aggerated tonus some of the nerves were severed. Three hours after the operation the child was able to stand (b); and fourteen days later it could walk normally (c). The woman in Figure 94 is not an acrobat, but is suffering from a disease of the spinal cord in the course of which the nerve paths that carry the tonus impulses are destroyed. In consequence the natural tension of the muscles has disappeared. Her leg is so flaccid that she can no longer stand, but lies paralysed in bed. Her leg can be raised far over her head because it has become loose at the hip. The child in Figure 93 and the woman in Figure 94 are the two extremes. Between them are the normal persons, among whom there are all gradations of hypo- and hyper-tonic individuals. Each one of us belongs to a definite tonus type. The tonus of the musculature is, so to speak, the external indicator of the "state of the weather" in the nervous system.

Muscle Sense. Each nerve fibre that transmits an order to contract from the brain to the muscle—that is, each motor fibre—carries a strong current. It corresponds to the lighting circuits of our homes. The tonic nerve fibres which transmit the weak but sustained tonus impulses carry a weak current like an electric-bell circuit. In addition to these there exists yet a third type of nerve fibre, the sensory fibre, which connects the muscle with the sensory centre of the brain. This nerve fibre corresponds

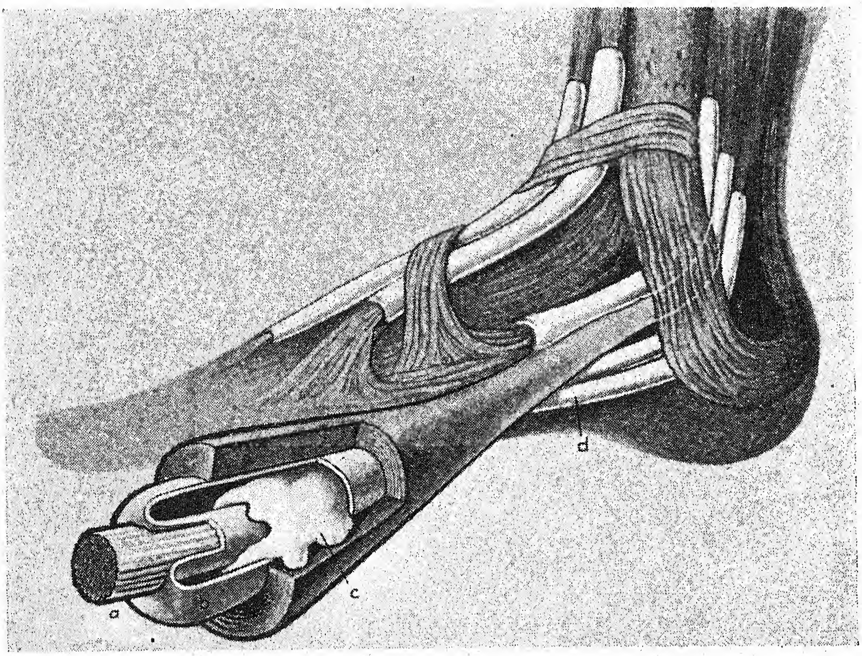


FIG. 96. *At (d) is seen one of the many tendon sheaths of the foot. The tendon (a) moves within a double-walled sheath of connective-tissue (b) containing a lubricating fluid (c), which reduces friction to a minimum, as in the motion of a well-oiled machine. A deficiency of this fluid, the result of over-exercise, may lead to painful inflammation.*

to a telephone line. By means of it the muscle reports to the brain its state of tension. Take this book in your hand and hold it up high. You know exactly where the book is, how it is shaped, and how heavy it is. When you move it, you know whether it is five inches or twenty-five inches from your forehead. This orientation in space is due to our muscle and joint sense. Every muscle of the arm and shoulder reports its degree of tension to the brain. On the basis of these combined reports the brain determines the exact position of the arm. In other words, the brain takes its bearings by means of these reports just as the position of an aeroplane or a ship, etc., is established with the aid of radio waves.

Automatic Control

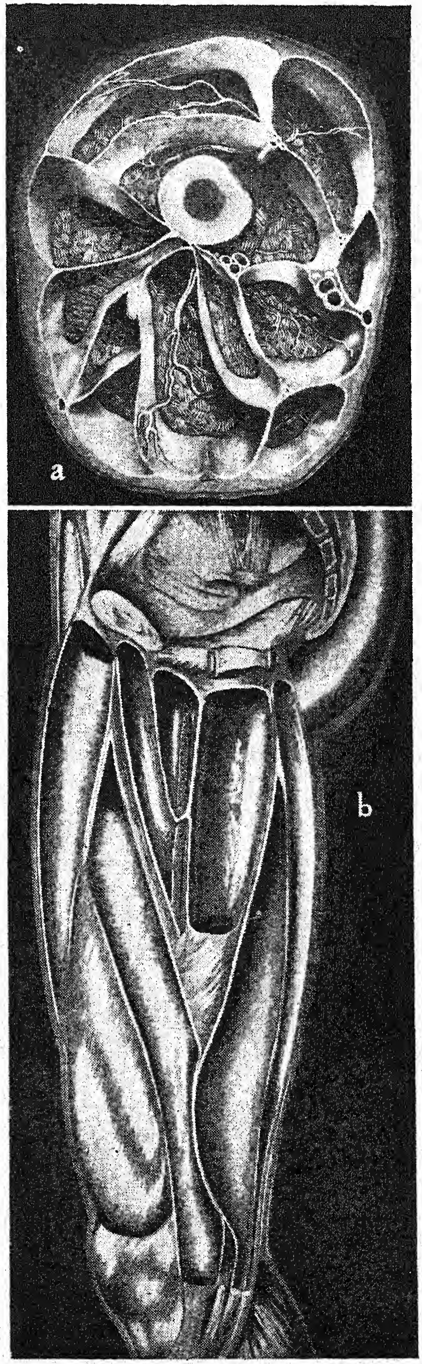
The muscle sense permits of our making movements without the need of controlling them with our eyes. We can go for a walk and converse with a companion or look at the street scenes without going astray or making a false step, because our muscle sense informs us of the position of our legs. If the telephone lines between the muscles and the brain are broken, as is the case in various diseases of the spinal cord, the individual loses his muscle sense and with it the ability to orient himself in space without the control of his eyes. An individual with a diseased spinal cord can stand during the day as long as he can see. As soon as he closes his eyes, however, he falls down. Usually these patients first come to the doctor with a complaint of this nature: "I can't understand it. When I turn off the light in my room, I feel very shaky!" Or they may say: "For some time now when I wash myself and close my eyes, I feel unsteady on my feet. . . ." These people have a partial loss of muscle sense. Soon even this last vestige disappears, and the patient can no longer walk, even in the daytime. He is paralysed. Yet he can be taught to walk again—with the aid of his eyes. Footprints are traced on the floor, and the patient then learns to place his feet exactly in the prints. In a similar manner he also learns to walk up stairs [Fig. 95].

The Space Sense

The accomplishments of the muscle sense are extraordinary. Stand up from your seat and set some goal for yourself several yards away, such as a door-knob, or a light-switch, or even a key in a closet door. Try to reach and touch this goal while keeping your eyes closed. You will be astonished at the almost somnambulistic assurance with which you can move through the room and reach a key or a switch four yards distant.

The world of the blind is without light, but it is not empty. It is filled with tonus and a sense of space. The ability to perceive space makes it possible for us to walk up a stairway in the dark, to take the right key from our pocket, and—what is really an astonishing achievement—to insert it correctly into the keyhole without looking. Women knit without watching the needles, typists type "by touch," automobile drivers shift gears without looking, pianists can play in the dark, and we can undress in the dark—all of these acts are in part functions of the muscle sense. Since space perception is a very delicate nervous function, it is a more delicate indicator of a person's freshness or fatigue than any other sign. If we observe ourselves attentively

FIG. 97. *Cylinders of the human muscle motor. (a) The sheaths of the thigh muscles in cross-section; (b) in longitudinal section.*



we shall soon notice that when we are tired our ability to orient ourselves in the dark is definitely diminished. If we come home tired, even though we have had no alcohol, we have more difficulty than usual in finding the keyhole or a light-switch.

Training. During a contraction a muscle is shortened by about $\frac{1}{16}$ its length. Each fibril raises one millionth of an ounce, and a square inch of muscle mass lifts about 58 to 140 pounds, depending on the training of the muscle. The development of a muscle is the best illustration of the training principle; indeed the word "training" has been adopted from the terminology of athletics, where the musculature of the body is certainly well exercised. Athletic accomplishments and records have constantly improved within recent years owing to the fact that athletic training has consciously been based on scientific principles. There is hardly a year in which world records are not broken. In 1906 in Athens runners from fifteen nations raced over an 800-metre course. Not one finished the race in less than two minutes. In 1936, 150 runners covered the same distance in less than two minutes. Most of these athletes were tall; only a few short men were in this group. This was quite natural. The former had long levers for locomotion, while the latter had short ones. In a manner of speaking, the former had been constructed by nature as express locomotives, whose wheels had long spokes. The latter were freight-train engines, whose wheels revolved just as fast or indeed even faster, but without attaining

such great speed. The smaller the wheel, the more rapidly does it revolve in relation to time and distance. The same is true of muscles. The smaller a muscle, the greater is the number of contractions in any unit of time. A violinist executes 10 movements per second. A pianist playing the "Minute Waltz" must move 740 keys with his right hand during one minute, and great virtuosos can accomplish this feat in 35 seconds. The smallest of the skeletal muscles of the body are the speech muscles, and they hold the record for speed: 25 movements per second! Because its muscles are still smaller, a fly moves its wings back and forth 330 times a second!

Tendons and Inflammation of the Tendon Sheaths. A large muscle that connects one bone with another is a model of the small fibre of which it is composed. Like the latter its basic shape is that of a spindle, and its surface is covered by a sheath so that it will not become abraded. The muscles do not lie free, but run in cylinders within which they are compelled to move exactly like the pistons of a motor-car engine [Fig. 97].

Muscle Cylinders and Pistons

The human body is a machine within which more than 500 cylinders are installed, and in which 500 red muscle pistons, equipped with numerous ignition apparatuses and conduction wires, slide back and forth. What a wonderful picture it would make if someone would take the trouble to represent them all together in the same manner as has been done with those in Figure 97!

As a result of being crowded together and of the traction to which they are exposed, the ends of the muscle fibres have become coarse and hard, forming white tendons that connect muscle with bone [Fig. 96]. Tendon tissue is very strong and firm. Get a piece of beef tendon from your butcher and boil it for an hour, or even eight hours. Then try to chew it. All your efforts will be entirely in vain.

Lubrication

In order to prevent the tendons from becoming abraded when in motion, they are enclosed in coverings, the tendon sheaths (d), at the danger points. The tendon sheaths are those points of the human motor machinery upon which the greatest demands are made when in use and which are therefore constructed with special care. The tendon sheath is a double-walled sac (b). The internal layer is intimately united with the tendon (a), while the outer layer is connected with the neighbouring organ. The space between them is filled with fluid (c). When a muscle moves, the two layers of the tendon sheath slide past each other with a minimum of friction like the piston and cylinder wall of a well-oiled machine.

The muscle machine needs rest periods so that the fluid spaces in the tendon sheaths may be replenished. If the muscles are used too long without a rest, the two layers of the tendon sheath begin to rub against each other. The tendon begins to creak just like an unlubricated motor-car axle. The result is a creaking tendon-sheath inflammation, an extremely unpleasant and chronic condition which occurs among athletes, musicians, dancers, stenographers, typists, and machine workers of all kinds. If one notices the slightest signs of fatigue or pain in the joints of the hands or feet, or if the joints begin to creak, they must

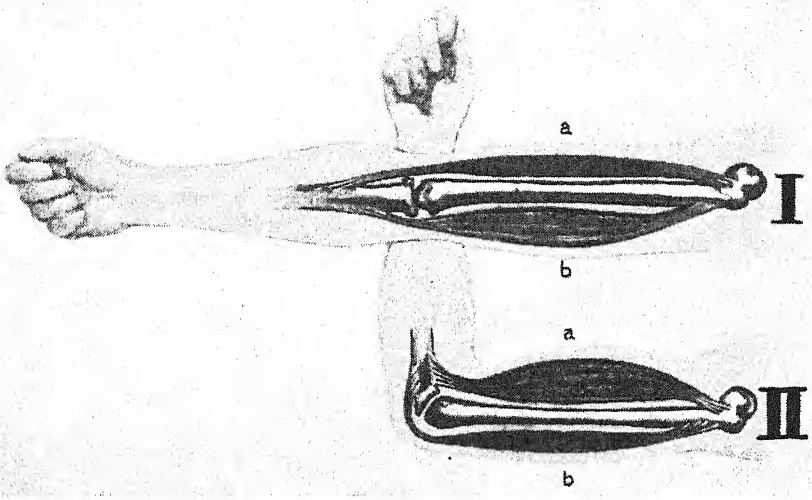
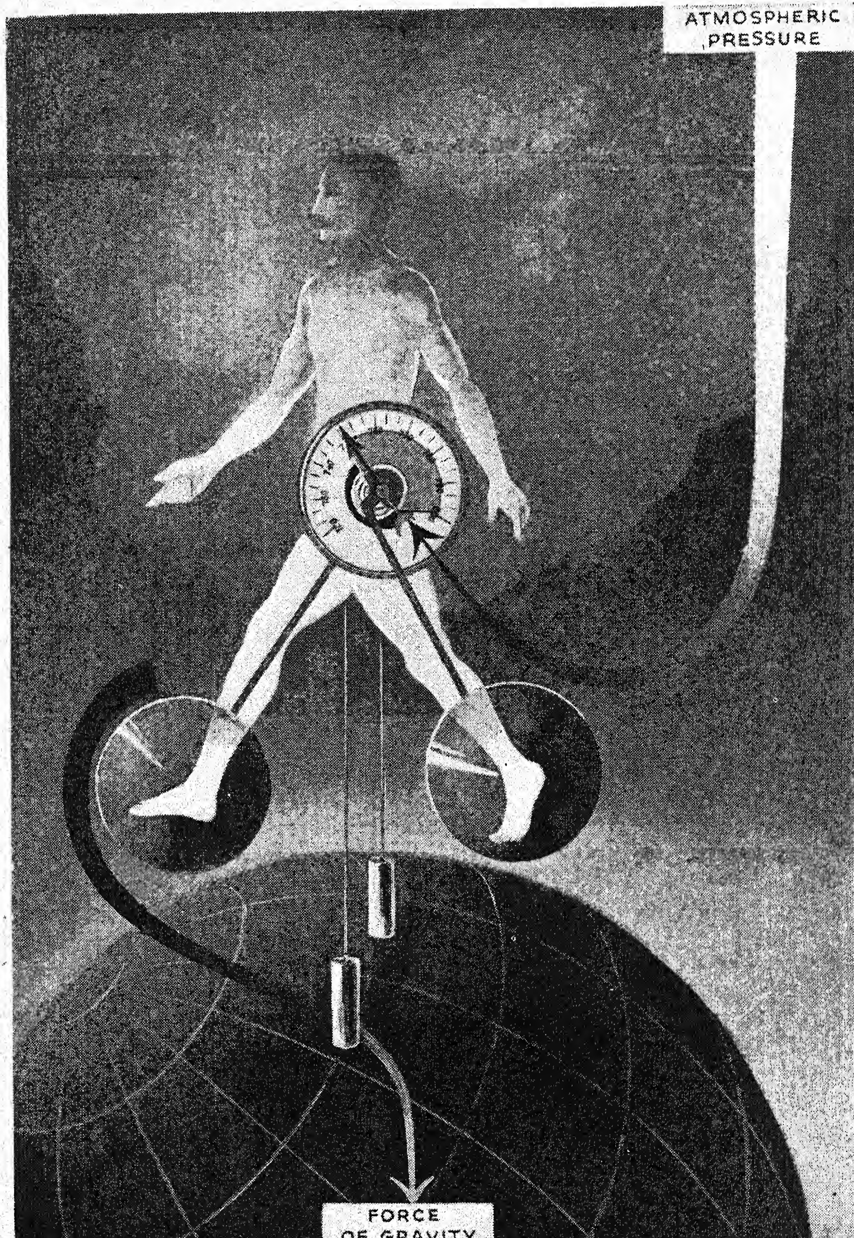


FIG. 98. *The pistons of the human muscle motor. At (b) is the triceps, which straightens the elbow joint (I); and at (a) the biceps, which flexes this joint (II).*

immediately be put at rest in order to prevent the threatening tendon-sheath inflammation. We all know by experience how difficult it is to decide on a step of this kind. Who likes to give up athletic activities or music studies for many weeks? Yet if a tendon-sheath inflammation is once present, a period of rest ten times as great is required before the condition is overcome.

Flexor and Extensor. Figure 98 depicts, as an example, one of the simplest working systems of the human musculature, the extension and flexion apparatus of the arm. The best known of all muscles, the biceps (a) is situated on the inner aspect of the arm, while its opposite, the triceps (b), is located on the outer aspect. If the arm is extended (I), the extensor muscle, the triceps, is shortened, and the flexor, biceps, is relaxed. If it is desired to bend the arm, the biceps is contracted while at the same time the triceps is relaxed (II). Flexor and extensor muscles are antagonists. When one contracts, the other relaxes.

The Human Muscle Machine. Figure 89 represents a lateral view of the most important external skeletal muscles. Figure 105 (a) shows the muscles of the back and the lumbar region, and Figure 105 (b) the muscles of the trunk. We can thus obtain some idea of the internal and external construction of the human muscle machine. The human body is a muscle machine with 500 pistons running in all directions, and several hundred driving belts guiding more than 36 transmission systems and moving over 100 joints—this gives one some idea of the difficulties involved in a study of the mechanics of the muscular system. In spite of all the intensive research that has been devoted to the subject, there are still many unsolved problems of muscle and joint mechanics. The layman must remain satisfied with the few glimpses that enable him to form some idea of the entire field.



MACHINERY OF WALKING

FIG. 99. *When we walk, atmospheric pressure forces the thigh bone into the hip-joint, thereby reducing its weight. The leg, raised by muscular contraction, is then attracted by the force of gravity, just like a swinging pendulum.*

CHAPTER IX

Principal Muscle Systems

THE MUSCLES OF THE HEAD. RIGHT-HANDEDNESS. ASYMMETRY OF THE LEGS. LEFT-HANDEDNESS. THE CAUSE OF ASYMMETRY. AMBICULTURE. THE MUSCULATURE OF THE TRUNK. THE ABDOMINAL MUSCULATURE. HERNIA. MECHANICS OF WALKING. THE ARM.

THE head is a rocking-chair, balanced at the top of the spinal column upon the runners of the uppermost vertebra [Fig. 60]. Since man is not built to be a standing creature, but is an upright quadruped whose head originally hung downwards like that of all animals, the centre of gravity of this "rocking-chair" is not located directly over the joint, but rather eccentrically with an excess of weight in the region of the jaw. Consequently, in order not to topple over forwards, it must be maintained in place by special muscles [Fig. 100]. The supporting muscles of the head are the muscles of the back of the neck.

Similarly the joint of the lower jaw is constructed for a hanging head. In an animal the lower jaw is in the normal hanging position. Man must pull on his jaw to keep it from falling down. The cheek muscle serves to support the jaw. This muscle can be felt more easily than any other muscle of the body if one places one's fingers on the cheeks, presses the teeth tightly together, and then moves this muscle. In nervous people who are excited, it can be seen vibrating restlessly. It is the most important masticatory muscle and as such one of the strongest in the body. In chewing coarse food it performs a quantity of work equal to one horse-power! The neck muscles supporting the skull, the cheek muscles supporting the lower jaw, and the lid muscles carrying the lids are three groups of muscles that are continually tensed in waking hours.

In the performance of these functions, however, the muscles are generally not under the control of the high-tension current of volition, but are automatically charged by a weak current from the tonus centre and are tonically contracted. If one grows tired and the tonus of one's muscles diminishes, fatigue first becomes noticeable in those muscle groups that are placed under special strain by the upright posture of man. The knees give way, the spinal column bends forward, head and jaw sag downwards, and the eyelids close. We nod off [Fig. 101].

Since the posterior neck muscles have to perform such heavy labour uninterruptedly for sixteen hours and longer daily in keeping the heavy sphere of the head in position, they are numbered among the strongest muscles of man's body. They are true heavy athletes, and among occupational groups may be compared with furniture-movers, while the neck muscles that direct the position of the head and the delicate movements of the face are light athletes, comparable to a chauffeur who sits

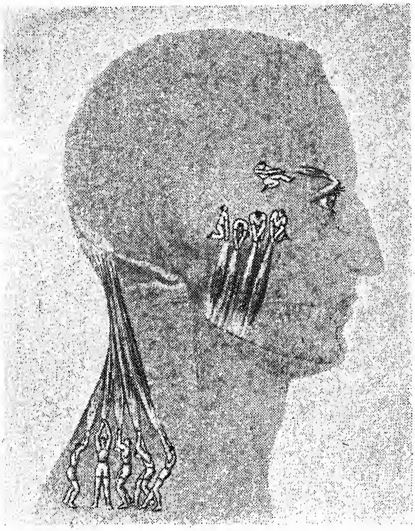


FIG. 100. *While we are awake, the muscles of the neck, cheeks and eyelids are working constantly in order to keep the head erect, the jaw up and the eyes open.*

at the steering wheel of a car and without performing any heavy labour steers the moving automobile round curves and street corners.

As a result of man's upright position several muscle groups of the head have become superfluous and are in a process of degeneration. Among these are the ear muscles with which animals prick up their ears; man no longer needs this function as he has become an eye creature. The ear muscles are still present, although but few people can still move their ears like animals. By means of exercise these muscle remnants can again be made to function. Wiggling the ears is a sport among schoolboys. When in the course of his lectures the famous anatomist Albinus discussed the ear muscles, it was his custom to remove his periwig and to wiggle his ears vigorously, to the great delight of his enraptured students.

On the neck directly under the skin lies a flat, extensive muscle with which handless animals shake off flies. The play of this muscle can be observed in any horse or ox. This muscle, too, is still present in man, but in a degenerate form. On the other hand, however, just because of the erection of man's head, and in conjunction with his speech, the more highly situated skin muscles of his face have developed, with a fineness not found in any other animal, and have created a separate muscle apparatus known as the mimic musculature. The mimic musculature consists of those muscles which man employs, without performing any specific acts, while speaking or in silence to express his inner feelings. It is that musculature by means of which a child contorts its face into a grimace. Since the forms of expression employed by an individual

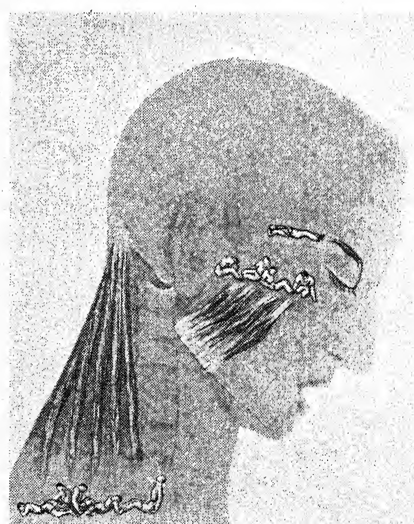


FIG. 101. *When we are tired, the neck, cheek and eyelid muscles relax, so that the head and jaw sink and the eyes close. Sleep usually follows immediately.*

are frequently repeated, the facial muscles come to assume certain permanent attitudes which, when taken together with the form of the skull, we call the physiognomy of the individual. If a profession or trade requires certain attitudes, a so-called professional physiognomy may appear. It is interesting to note that happily married couples often come to resemble each other.

Facial Asymmetry. Stand in front of a mirror and observe your face; it is not symmetrical. In ninety-six per cent of all people the right half of the face is more markedly developed than the left. The arch of the right eyebrow is higher, the forehead is squarer or more curved on the right side, the right cheek is more prominent, the mouth, the eye, and the ear are moulded with greater precision. If we were to look closely at all the people whom we know, similar asymmetries would be observed.

Right-Handedness. Asymmetry of the head is part of the asymmetry of the entire body. In the embryo the body develops symmetrically, and no asymmetries are to be observed in the newborn. Around the age of six months, however, when the child begins to use its hands, it shows a preference for one hand over the other. Ninety-six per cent of mankind prefer to grasp, write, and work with the right hand. They are right-handed. Our entire style of living is based on this fact of universal right-handedness.

Asymmetry of the Legs. The legs also differ in strength and dexterity. The heart is situated on the left side and the liver on the right. Thus the structural equilibrium of the body is already disturbed internally. As we know, the skeleton is not rigid and unchanging, but rather a plastic structure, so that this asymmetry leaves its mark on the spine, the pelvis, the thighs, and the feet. When buying a pair of shoes, both shoes

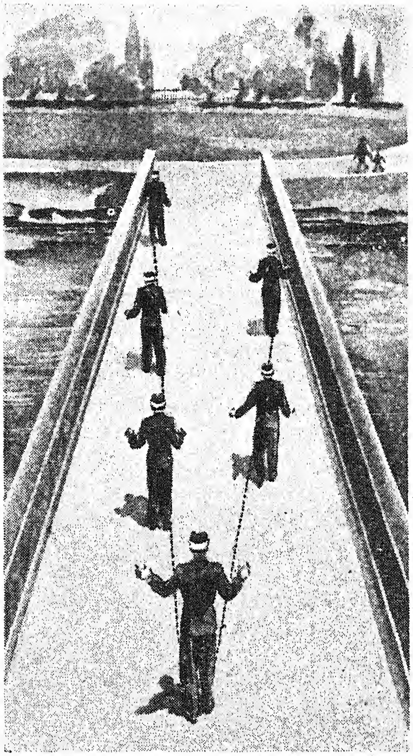


FIG. 102. *A hopeless experiment. Owing to the asymmetrical structure of the body and the consequent lack of symmetry in the gait, it is impossible to walk blindfold over a narrow bridge without colliding with the railing on one side or the other.*

must be tried on, because the measurements of the feet often differ greatly. On closing the eyes one becomes incapable of walking in a straight line. Even if a fantastic sum were to be offered to any person who could walk blindfolded across a narrow bridge, such as that in Figure

102, without touching the railing on either side, one can be sure that the prize would remain unclaimed. Even much less exacting experiments are unsuccessful. Without the control of the eyes one cannot reach a tree at a distance of thirty paces.

St. Mark's Square in Venice is about 194 yards long and 82 yards wide; certainly room enough for anyone who wishes to cross. Yet in the course of experiments that were carried out there, not a single one of the people tested succeeded in crossing from one narrow side of the square to the other with eyes closed. Asymmetry of the body and therefore of the musculature is believed to be the reason for the wandering about of people when they are lost. In Sweden, where snow and fog often occur together, and tracks can be traced, reliable observations have been made on the wanderings of lost men and animals. On a foggy night three people wanted to cross a valley two and a half miles wide. Yet they were unable to do so, but wandered around in a circle four times, and finally—arrived back at the hut from which they had started [Fig. 103]. While travelling through the Tibetan desert the explorer Sven Hedin was overjoyed to find footprints. On closer examination they turned out to be his own. Owing to fatigue, he had not looked at his compass for several hours and had travelled in a circle. In his story *Master and Man* Tolstoy describes an involuntary sleigh-ride in a circle. Wild animals circle about the area where they live, because of their asymmetrical bodily structure. They never run straight ahead but return almost automatically to their starting point as a result of circular movement.

Likewise, without constant ocular control and correction one can neither row straight ahead nor drive a car along a straight line. The very poor results that have been ob-

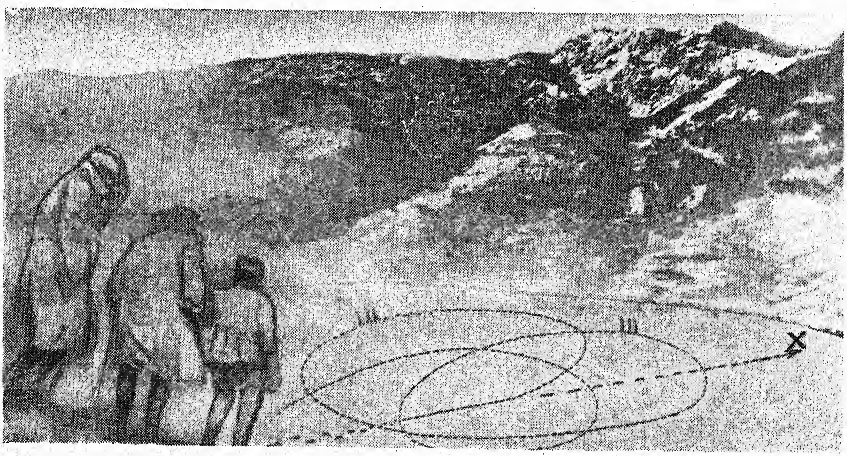


FIG. 103. *The results of asymmetry: every blind wandering ends in a circle. Here are the tracks of three men who attempted to cross a valley to X during a snowstorm. Repeated but futile attempts have led them back to the point from which they set out. The constant control of the eyesight is necessary to correct the deviation arising from bodily asymmetry—the unequal development of opposite sides of the body.*

tained in attempts to drive cars while blindfolded are very astonishing. After a short start every person tested became uncertain and, as a victim of asymmetry, began to drive in regular circles. The radius of such circles was often no more than thirty-three yards, and yet the driver was convinced that he had driven the car in a straight line.

Left-Handedness. Ninety-six per cent of all persons are right-handed. In four per cent the situation is reversed. They are left-handed. Left-handedness is neither a defect nor a vice, but simply an inversion. If one notices that a child is left-handed, it ought not to be scolded, nor should the completely useless attempt be made to transform the child into a right-handed one by means of compulsory measures or repeated commands. Don't be dissatisfied with the situation. It is possible that the child may be especially talented, for left-handedness is very often combined with special talents. Leonardo da Vinci, undoubtedly one of the most remarkable and many-sided figures in the history of human culture, was left-handed to such a degree that he even kept his notes in mirror-writing.

Michelangelo, the greatest sculptor of all time, worked with his left hand; Holbein and Menzel painted with the left hand. Left-handedness is mentioned several times in the Bible. Among the fighting men of the tribe of Benjamin there were seven hundred who were left-handed; "every one could sling stones at an hair breadth and not miss" (Judges xx, 16). Ehud, the leader of a delegation, used his left-handedness to assassinate Eglon, King of Moab (Judges iii, 15-22). Unnoticed, he drew his sword with his left hand from beneath his cloak and stabbed the tyrannous ruler. Achilles likewise fell a victim to a left-handed adversary.

The Cause of Asymmetry. We are ignorant of the cause of asymmetry. There are about twenty-five, in part very ingenious, theories on the subject. It is well to note here that while

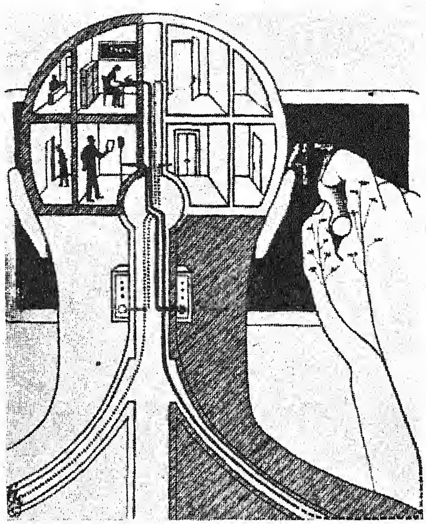


FIG. 104. *Man is right-handed because he is left-brained. Our speech, writing and actions are controlled and directed by the left half of the brain. The nerve fibres cross in the medulla oblongata, as shown above.*

a theory may appear convincing, and all the examples cited in its support may be correct, yet the theory can still be false. A theory is of no more value than a balance sheet. The figures may be correct; the accounts may appear to be accurate; discrepancies may be absent. Yet the figures cannot tell us whether the properly drawn-up balance sheet is a faithful reflection of the actual conditions existing in the enterprise. All theories of right-handedness that try to elucidate the problem on the basis of such

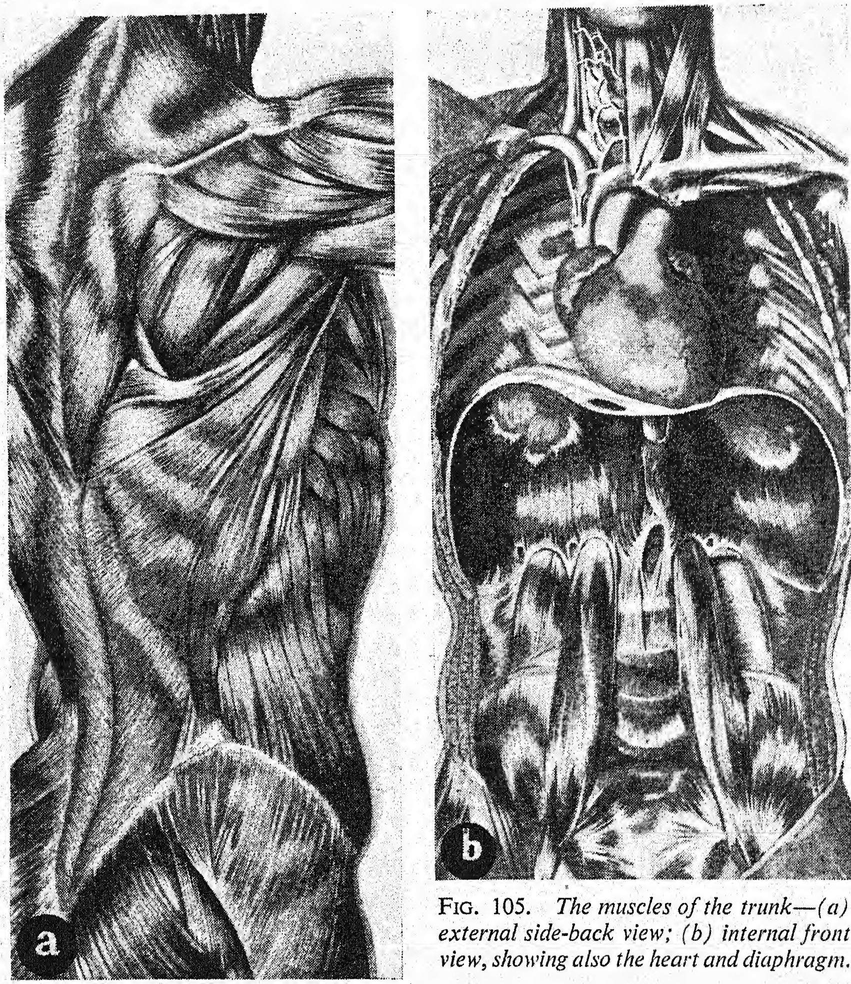


FIG. 105. *The muscles of the trunk—(a) external side-back view; (b) internal front view, showing also the heart and diaphragm.*

external factors as modes of living, training, and cultural customs have been superseded since it was discovered that right-handedness is not due to any structural asymmetry of the body, but is based on an asymmetry of the brain. The human brain is indeed symmetrical in its structure, and consists of a right and a left half, but these halves are not equal functionally. The left half of the brain is believed to be predominant over the right. The descending and ascending nerve tracts that connect the brain with the rest of the body pass from one side of the spinal cord to the other at the level of the neck and emerge on the opposite side of the body [Fig. 104]. The right half of the brain supplies the left half of the body, and vice versa. Since the left half of the brain predominates, the right half of the body is more skilled. Not only are we right-handed, but we are also "right"-speaking. We have our chief speech

centre in the left half of the brain. However, a subordinate speech centre is located in the right half of the brain. The situation may be illustrated pictorially as in the accompanying Figure 104. The rooms on the left side are occupied and the people in them are carrying on their activities. The suite on the right side is empty. If it becomes necessary, however, the people and activities on the left side can be shifted to the right, and after some readjustments everything goes on as before. Thus if an individual suffers a gunshot wound of the left parietal convolution, he loses his motor speech centre and is unable to speak. After a while, however, the right centre may take the place of the injured one, and he learns to speak again.

Special Centres

In conjunction with the speech centre, special centres for reading, writing, calculating, for remembering words, numbers, and ideas, as well as centres for word-formation and linguistic combination have developed in the left half of the brain, so that man not only writes, speaks, and works predominantly with the left half of the brain, but also thinks with it. In left-handed individuals the situation is reversed. They have their chief speech centre in the right half of the brain and lose the ability to speak if the right brain is injured.

Ambiculture. If the left half of the brain is injured in childhood as a result of accident or disease, the affected child does not necessarily become mute. Even if the ability to speak is lost at first, the child learns to speak again. This is due to the above-described ability of the right half of the brain to assume the functions of the left half. On the basis of this experience the demand has been raised that children be trained to use both hands with the ultimate intention of developing both halves of the brain equally. This idea has been named ambiculture to indicate the equal development of both sides of the body.

An Interesting Theory

A great deal has been written on this problem and it has been widely discussed. As always the advocates of ambiculture claim to have achieved special successes. Yet as often happens with new and wonderful theories and methods, the discoverers appear to themselves to be successful, but their good results are not apparent to other people. It has not been possible to train many children to become more capable by means of ambiculture. Nevertheless the idea ought not to be rejected as worthless.

The Musculature of the Trunk. Figure 105 presents two views of the trunk musculature of the human body. Figure 105 (a) shows the muscles of the back as seen from without. We see how the muscles cover the skeleton in the form of broad sheets, how the fibre bundles run in various directions towards numerous points of insertion—no motor mechanism in the world of technology has a structure so complicated as that of the human body. Figure 105 (b) represents a view into the opened trunk. In the centre lies the heart. It rests on an arched muscle plate, the diaphragm. The latter is supported by high muscle columns, and descends by contracting its fibres as well as these columns. The diaphragm forms the roof of the abdominal cavity and the floor of the thorax. When it descends, the

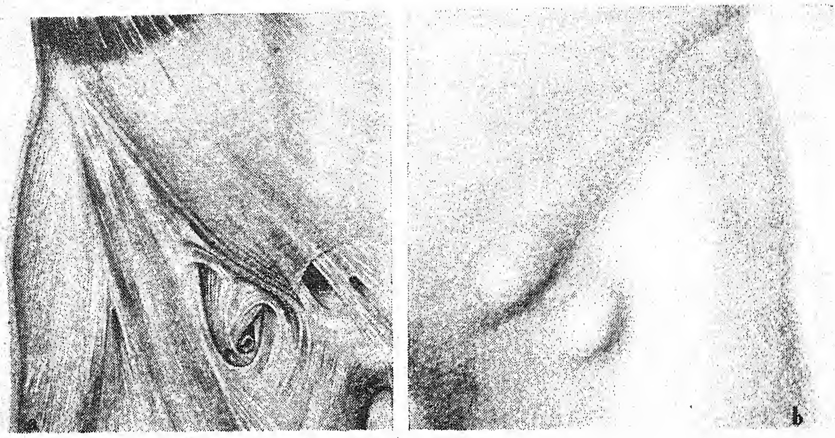


FIG. 106. *Inguinal hernia (I). At (a) is shown the inguinal ring in the abdominal wall after removal of the skin and the subcutaneous fat. The external swelling in the groin, characteristic of this type of hernia, is seen at (b).*

abdominal cavity becomes smaller and the thoracic space larger. If the thoracic cavity becomes larger, the lung spaces expand, the air-pressure in them sinks, and the outer air flows into the lungs. When the pull of the respiratory muscles decreases, the diaphragm rises, lifting the floor of the lungs and pressing out the air.

The breathing body is an air-pump, and the diaphragm is the muscle piston which travels back and forth within the trunk alternately enlarging and decreasing the thoracic and abdominal cavities, thus creating positive and negative pressures. The diaphragm is important for the support of life, and is at the same time the most industrious muscle in the body. It functions from the first to the last minute of our lives, when we are awake and when we sleep. Its only rest periods are the short pauses between breaths. In the course of a lifetime the diaphragm executes approximately five hundred million movements.

The Abdominal Musculature. In the intervening space between the thorax and the pelvis, the musculature of the body plays a unique role. Instead of taking part in the locomotor mechanism of the body, its function is that of support; in the form of the abdominal wall it must keep the entire visceral system together as in a sack. The wall of the abdomen consists of several flat layers of muscle, wrapped around the body in criss-cross fashion, and reinforced by strong tendon strips and plates [Fig. 105]. In order to be able to fulfil their function, the abdominal muscles must be taut and elastic.

In youth this is normally so. If in the course of an individual's life, however, the abdominal muscles are put under too great a strain, or on the other hand if they atrophy as a result of too little use, they yield to the intra-abdominal pressure and relax. The result is a pendulous abdomen. Women are more prone to this disfigurement than men. If a woman's abdominal musculature is not sufficiently strengthened, or if a mother cannot rest sufficiently after the birth of a child (as is unfortun-

ately true of many women at the present day), if she gets up too soon after confinement or miscarriage and undertakes heavy work, the abdominal wall may become relaxed. This is a widespread condition among older women.

During the act of coughing, during a bowel movement, as well as during the birth of a child, the abdominal muscles contract in their entirety to achieve the maximum pressure. Interrupt your reading for a moment; cough and at the same time observe what the abdomen does. By means of this experiment on your own person you will obtain a clear impression of the nature of the work performed by the abdominal wall.

Hernia. The abdominal wall has several weak points. The weakest ones are located at the inguinal fold, the boundary between the abdomen and the thigh, and are known as the inguinal rings [Fig. 106 (a)]. Sometimes these inguinal rings relax in individuals whose connective tissue is poorly developed, or who strain their abdominal muscles excessively. In consequence the intestines pass out of the abdominal cavity through these rings, so that they come to lie outside the muscle wall and may be felt as swellings under the skin (b). This abnormal condition is known as an inguinal hernia [Fig. 107 (c)]. Inguinal hernias are observed in infants whose abdominal rings were not sufficiently closed up at birth, in young people with poorly developed connective tissue, among athletes who strain their abdominal wall, among older people in whom—because of their occupation or chronic constipation—the intra-abdominal pressure is excessive, and among women whose inguinal rings cannot resist the pressure resulting

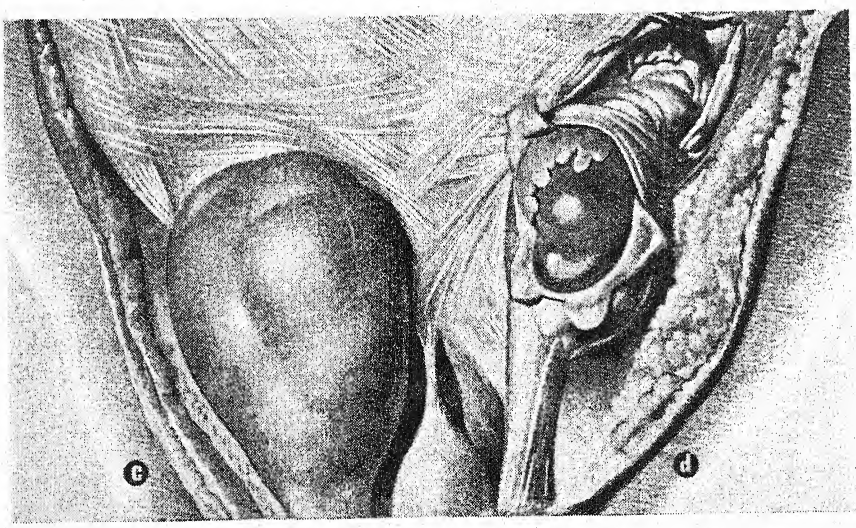


FIG. 107. *Inguinal hernia (II). The appearance of a very large inguinal hernia after removal of the skin (c). At (d) is shown how an inguinal hernia appears after the opening of the hernial sac. Beneath the covering layers (here partly removed) can be seen a portion of the intestine. During the operation this protrusion is returned to the abdominal cavity. The opening in the abdominal wall is then closed.*

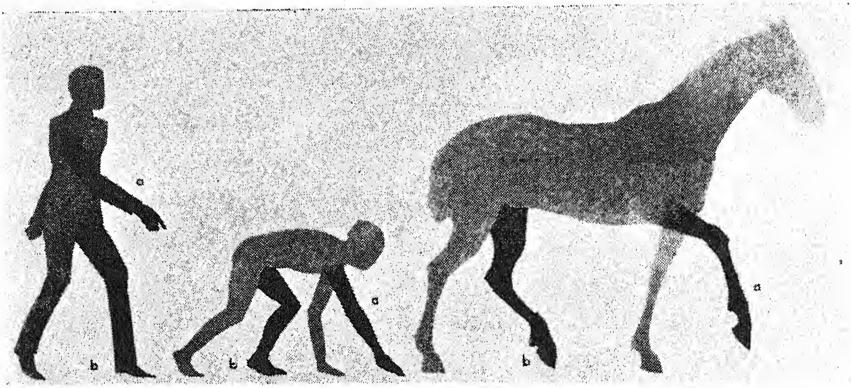


FIG. 108. *Man is an erect quadruped. In walking he swings his limbs much as other quadrupeds do. He leaves not only foot tracks, but—in the air, if we could see them—hand tracks as well. It is very difficult to walk while swinging the arms in any other rhythm.*

from labour pains during confinement. A hernia can be impalpably small and reveal its presence only by the pain which it causes; it can also be so large that it hangs like a sack from the abdomen. Larger hernias can be kept back by means of a truss. A truss is advisable for older people who do not wish to submit to an operation. Unless contra-indicated for special reasons, a young person should have a hernia removed as soon as possible by means of an operation. The more recent the hernia, the better are the conditions for operation, and the younger the individual, the greater is the healing power of the body and the less serious the operation. For young people the removal of a hernia is not only a medical and physical matter, but also a psychological problem, a question of joy in life. A hernia operation, one of the oldest operations in the history of medicine, in view of the present state of surgery can in general be regarded as relatively harmless. Anyone who has a hernia larger than a plum and engages in athletics, performs heavy labour, etc., exposes himself to the danger that the intestinal loops may become incarcerated in the inguinal rings. If the loops then become distended with intestinal contents or gas, it becomes impossible for them to return to the abdominal cavity through the narrow opening of the hernial sac. As a result they become swollen and inflamed, giving rise to the extremely painful and, under certain circumstances, very grave condition of strangulated hernia, which requires an immediate and no longer harmless operation.

Man Walking — a Pendulum Machine. Stand in the middle of the room, close your eyes, and consider yourself closely. No person stands like a stone pillar. The command "Stand still" exists only in our speech. The so-called act of standing is a constant process of balancing that extremely labile and, one can truly say, very precariously constructed bone tower known as Man. Laboriously we maintain ourselves in an upright position by constantly changing from one leg to the other, by constantly varying the pres-

sure on the joints, and by submitting our position to the continuous supervision of the muscle and joint sense.

The maintenance of balance requires about three hundred muscles. A horse can rest and sleep in a standing position because it stands like a table on four legs, thus reducing the work of its muscles to a minimum. Man does not rest, but works while standing. Standing is about as tiring as walking; indeed, since it does not occur in an automatic rhythm like walking, but requires delicately graded alternations of muscle tension, it may be even more fatiguing.

The walking of an upright man on his thigh-stilts [Fig. 67] is a real trick, at which we do not marvel only because we have all learned it. As is well known, anything that one learns to do is no longer regarded as difficult. If one were to ask an acrobat whether it is difficult to ride a bicycle on a tight-rope while opening a bottle of lemonade at a height of a hundred feet, he would laugh and say: "No, I've been doing it daily for fifteen years. It is not hard, but one must learn how to do it." Everybody would say the same about walking if four-footed visitors were to come to the earth from some other planet and regard our walking on our leg-stilts with astonishment. Nevertheless it remains a clever trick, and every engineer who has occupied himself with the mechanics of walking has marvelled at it.

In walking, man makes use of two natural forces: air-pressure and gravity [Fig. 99]. Each joint uses

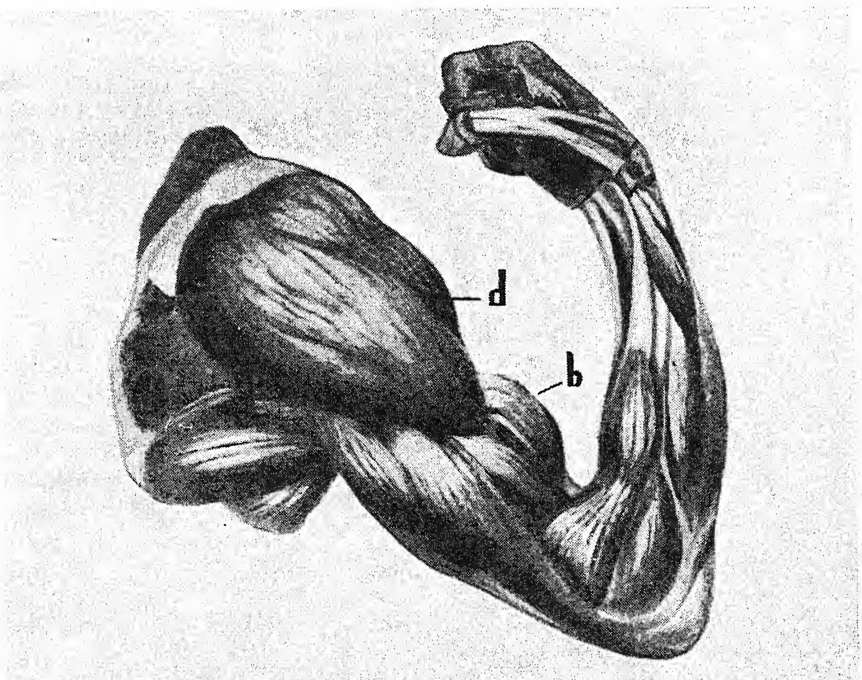


FIG. 109. *The muscle of a highly developed human arm can deal a blow of immense power. At (b) is the biceps, at (d) the deltoid. Compare this illustration with Fig. 98.*

air-pressure. Since it arises within a hermetically sealed joint capsule, and is consequently devoid of any air, every joint is under the pressure of the atmosphere—but no joint to a greater degree than the hip-joint. The head of the thigh-bone fits so ideally into the socket of the hip-joint and is enclosed by the latter to such a degree that a leg, weighing about twenty-two pounds, hangs from the body almost as if devoid of any weight. If all the ligaments are cut, the bone still remains in the joint. The stronger the atmospheric pressure, the more securely is the thigh attached to the body. When the atmospheric pressure is high, we don't feel the weight of our legs so much. When the weather changes and the atmospheric pressure falls, we feel that our legs are much heavier. This feeling is an accurate reflection of the situation. If it were

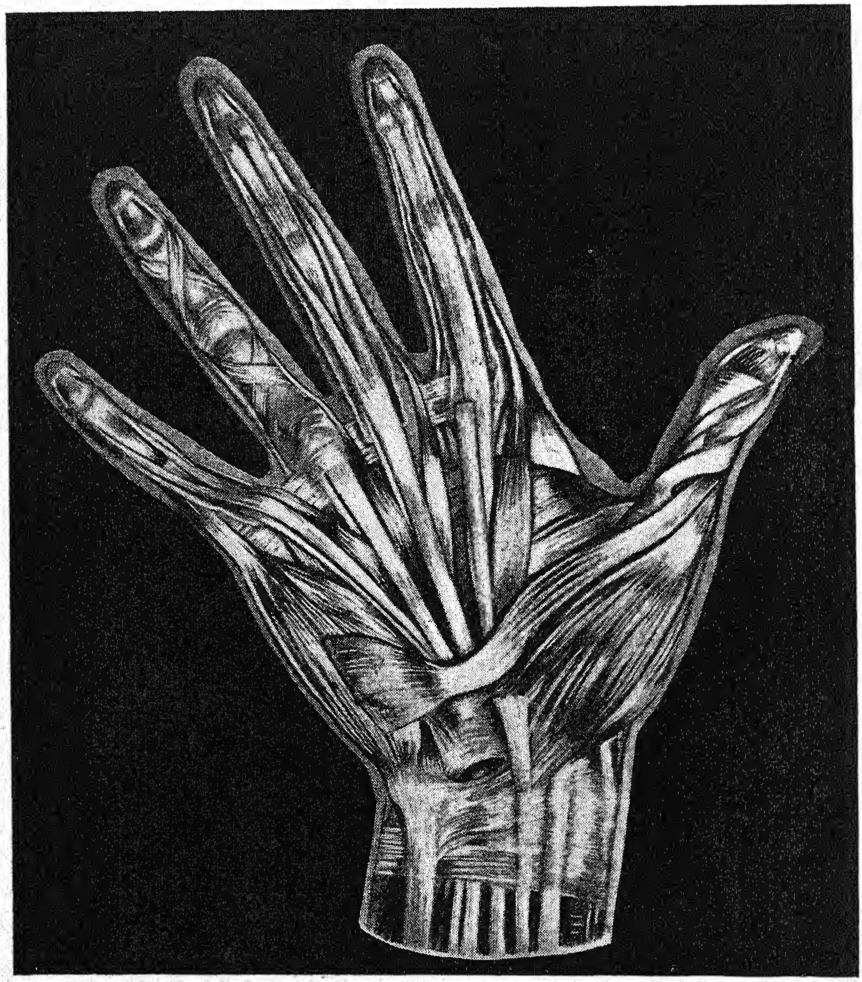


FIG. 110. *The muscle apparatus of the hand—one of Nature's masterpieces of technology.*

possible to install a spring with an indicator in the hip-joint, one could read off the air-pressure as from a barometer [Fig. 99].

The second natural force of which man makes use in walking is the gravitational attraction of the earth. The earth pulls the leg downward, after it has once been raised through the power of the muscles, and keeps it swinging like a pendulum. A walking man is a pendulum machine that renders his oscillating legs as light as a feather with the aid of a vacuum, and uses the earth as a counterweight.

Still a Quadruped

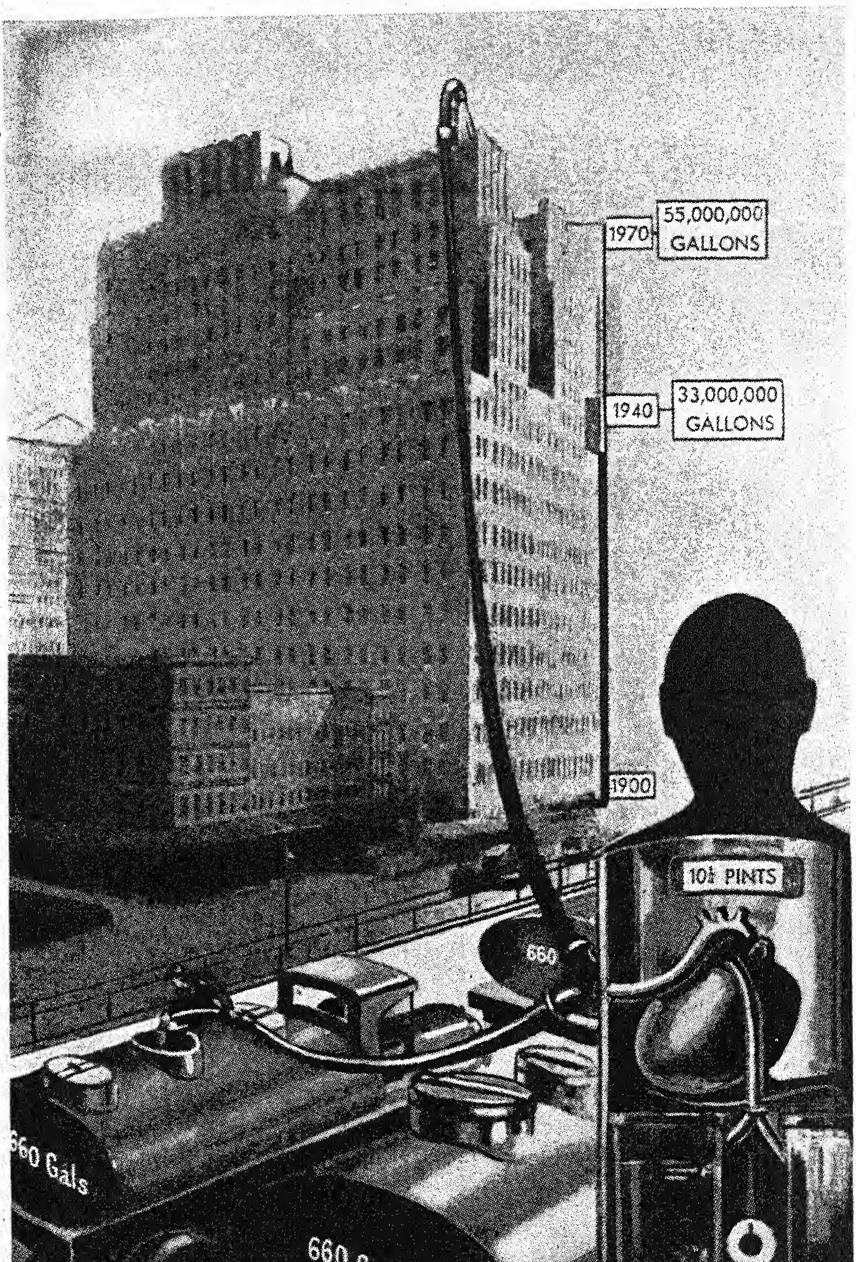
Man walks on two legs, but in a certain sense he has nevertheless remained a quadruped. We are quadrupeds whose forelegs walk in the air and not on the ground. While walking, each arm swings in time with the leg on the opposite side of the body, thus corresponding to the mode of progression in most other mammals [Fig. 108]. This cross-gait is deeply rooted in our being. Hardly anybody can walk fifty paces while moving the arms in a rhythm differing from that which we have inherited.

The Path of Life. Each step requires an energy expenditure equivalent to over eleven pounds. Anyone marching for nine hours performs a quantity of work with which half a million briquettes could be raised from the floor to the height of a table. On the average, an individual takes twenty thousand steps daily; in eighty years the total would be about five hundred million!

The Arm. The upper part of the arm is adapted for strength, the lower part for mobility. The farther one passes from the shoulder, the weaker, but also the more delicate and complex, does the mechanism of the arm become. The scapula is a relatively large turntable supported and controlled by giant muscles. If it has been sufficiently trained and developed, the upper arm is an almost terrifying muscle apparatus. One can readily believe that an arm like that in Figure 109 could deliver a deadly blow. The giant, triangular mass of muscle directly below the shoulder (d) is the deltoid muscle, so called because of its resemblance to the Greek letter delta (Δ). The two swellings beneath it (b) are the bellies of the biceps, which serve as an indicator of muscular development. In a man of moderate strength, the circumference of the arm above the biceps when extended is about 11 inches, when flexed about 12.5 inches. In athletes these measurements can be increased to more than 18 inches.

Man's Wonderful Hand

In the forearm, as at no other point in the body, dozens of elongated muscles crowd together and pass in compact groups through the narrow strait of the wrist to the hand. The entire structure resembles the entrance to a station. However, no trains travel back and forth on the rails, but rather the rails themselves are mobile. In the palm of the hand the muscles again expand and branch out to reach the fingers. In order for the muscles to maintain precisely the same course at all times, they are kept in place by a large number of ligaments and sheaths. Not only is the appearance of the entire apparatus very complicated, but it is also æsthetically very pleasing [Fig. 110]. The study of the forearm and the hand may be included among the most difficult sections of anatomy.



THE AMAZING PUMP WITHIN OUR BODIES

FIG. 111. *During a day the heart pumps over 2,500 gallons of blood, and during an average lifetime about 55 million gallons—equal to the cubic capacity of a skyscraper.*

IV: THE CIRCULATION OF THE BLOOD

CHAPTER X

The Heart

MAN A COMBUSTION ENGINE. THE CIRCULATION OF THE BLOOD. THE HEART. THE VALVES OF THE HEART. THE "PRIMUM ORIENS." THE WALL OF THE HEART. THE CORONARY VESSELS. THE PULSE. CARDIAC NERVES. HEART SOUNDS. THE NERVOUS HEART.

REGARDED as a machine, man is a combustion engine like a petrol or steam-engine. Combustion is a chemical process which consists essentially in the circumstance that molecules of atmospheric oxygen (O) penetrate into the atomic structure of a carbon-containing molecule, unite with the carbon atoms (C) to form carbon dioxide (CO_2), and thus cause a breakdown of the atomic structure. As a result of this breakdown the internal potential energy of the molecule is liberated in the form of heat. This heat is the yield of the combustion process. Coal is burned in a steam-engine, petrol in a petrol-engine, and food consisting of sugar, flour, and fat in the human body. Figure 112 (I) is a diagrammatic representation of the human combustion engine. This diagram is fundamental for an understanding of the vital processes of the body, and should be studied very closely.

It will be seen in the diagram that the body is traversed by three tubular systems. They are:

The intestinal canal (shown in white) which receives the carbon-containing fuel substances (C);

The air canal (light grey) for the reception of oxygen (O_2);

The blood canal (dark grey) which conducts the two substances C and O_2 to the place where they unite and are burned, as, for example, in the muscles. Since the blood circulates within this canal, which consists of two inter-related canal systems that may be represented schematically in the form of the figure "8," it is known as the circulatory system. The tubes or pipes forming the canal are called the blood vessels, the fluid within them the blood. At the point where the two circles of the figure "8" intersect is a pump, the heart, which drives the blood through the tubes.

After having learned of the existence and relations of these three tubes, let us now follow the course of the combustion process by means of the numbers in Fig. 112 (I). The fuel (C) enters the mouth with food and collects in the stomach and intestine. From the latter organs it is carried to the place where combustion takes place. In order to burn up the deposited fuel, an individual breathes in air containing oxygen (1). The

air passes through the respiratory passages (2) into the interior of the lungs (3). Here the most delicate terminal branches of the respiratory tract come into contact with the equally delicate branches of the vascular system. Oxygen now passes through the thin walls of the respiratory passages into the arterial blood vessels (4). The circulatory blood carries the oxygen (5) to the spot where combustion takes place (6). Here oxygen (O_2) unites with carbon (C) to form carbon dioxide (CO_2). Heat is produced during this union, and for this reason the process is termed combustion. The carbon dioxide flows with the blood (7) to the lungs (8), passes into the respiratory passages (9), and leaves the body by way of the nose (10). If one familiarizes oneself with this diagram so that it can be redrawn from memory, it will be easy to comprehend the complex diagram of the circulation presented in Figure 112 (II).

The Circulation of the Blood. The heart (7, 3) must drive the blood through the two circles of the figure "8," and has therefore divided itself into two parts. The right half of the heart has only to pump the blood through the smaller pulmonary circulation, and is consequently not so strongly developed. The left half of the heart (3) drives the blood through the greater systemic circulation of the body, and so is much stronger.

Circulation of Oxygen

Let us follow the path of one of the white oxygen spheres (O_2). It enters the body with the inhaled air by way of the nose (1) and passes into the lungs. Here it passes from the respiratory passages into the blood-vessels, and flows with the blood (2) to the left half of the heart (3). From the heart it is carried by the aorta (4) and the other arteries to the place where combustion takes place (5). At that point two white oxygen spheres unite with one black carbon sphere to form the black-white symbol of carbon dioxide. The latter now passes by way of the veins of the body (6) to the right half of the heart (7), whence it is transported to the lungs. Here the carbon dioxide passes into the respiratory tract (8) and leaves the body by way of the nose.

The Path of Carbon

After having traced the path of oxygen, let us follow the path taken by carbon (C), which enters the intestinal canal (white) from the outer world and is first of all deposited in the stomach (9). From the stomach it is transported to the intestine, where it is absorbed by special vessels. However, these vessels do not carry the carbon directly into the circulation, but first to a customs station, the liver (10), where the imported fuel is examined and worked on in several ways. Now the nutritive substances are first admitted into the circulation beyond the liver, and enter the right half of the heart (7). They are then transported to the left half of the heart (3) by way of the pulmonary circulation, and are carried by the arteries (4) to the place where combustion occurs (5).

The Heart. The blood-vessels that make up the circulatory system are not hard and unyielding, but flexible, rubber-like pipes. Their walls are composed of muscle fibres, and in fact blood-vessels are simply elongated, hollow muscles.

The heart is the inflated, balloon-shaped, central portion of the vascular system. By means of rhythmical

contractions this balloon drives the blood through the vessels. When it contracts, it expresses the blood which it contains; on relaxing, blood again flows into it. Among higher animals the blood must be directed in a certain direction by means of valves. These valves of the heart have been developed step by step in the course of animal evolution. Figure 113 shows the two kinds of cardiac valves in their various positions; Figure 114 shows them functioning within the heart. The ventricle (II) of the heart has two valves, one at its entrance (1), the other at its exit (2). The valves open only in the direction of the blood stream and compel the blood to flow exclusively in the one direction. The passage of the blood through the heart occurs in four phases:

(a) The vessel which brings the blood to the chamber (I) is full, the ventricle itself (II) is empty;

(b) The ventricle expands and admits blood from the vessel. The inflowing blood helps to open the valve (1) by its forward pressure;

(c) The filled ventricle contracts.

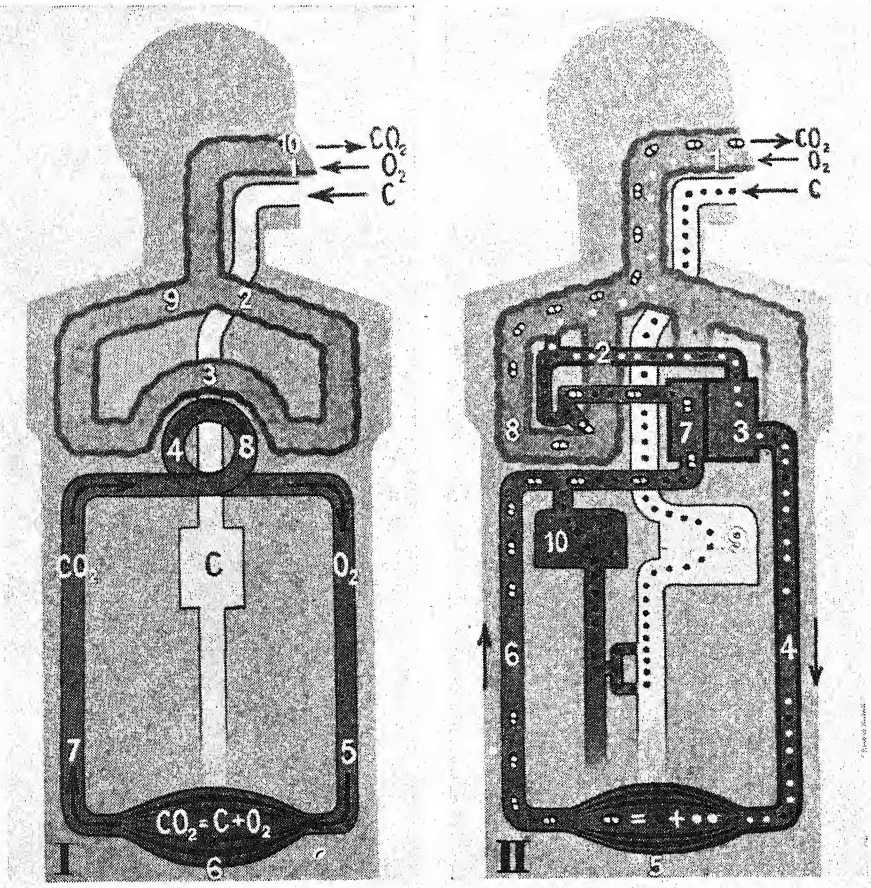


FIG. 112. *(I) The life cycle of the human body; (II) the circulation of the blood.*

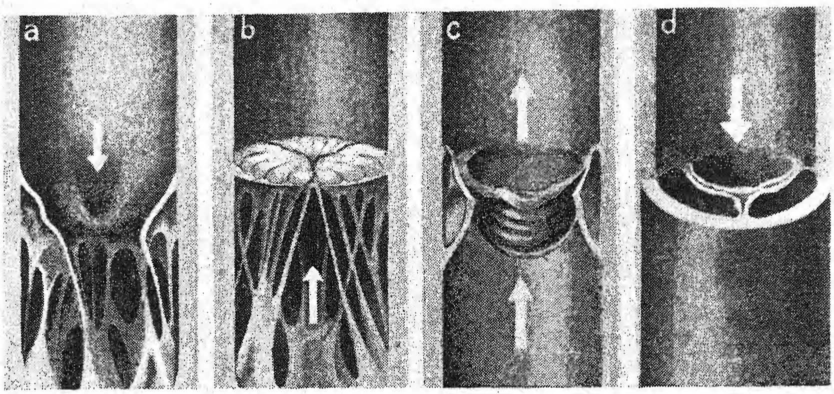


FIG. 113. *The cardiac valves. An auriculo-ventricular valve, when open (a); an auriculo-ventricular valve, closed (b); a semi-lunar valve, open (c); a semi-lunar valve, closed (d). By opening only in the direction of the blood-stream, the valves ensure that the blood flows in one direction only; a healthy cardiac valve permits no backward flow.*

The pressure of the blood closes valve (1) and opens valve (2). The blood is unable to return and must flow on between the leaves of valve (2);

(d) Now the blood-vessel beyond the ventricle (II) is filled with blood. The heart is empty. It expands and causes inward pressure at both valves. However, the blood that has left the heart cannot return because valve (2) closes under the pressure of the column of blood above it. Valve (1), however, opens again and lets new blood flow into the ventricle.

In the living body it is much harder to survey the relations of the various parts of the heart. Anyone who wishes to study the detailed structure of the heart can do nothing better than to buy a cow's heart at a butcher's shop and dissect it. Indeed, it is a very fine and interesting, but by no means easy, subject to study.

A view of the interior of the heart in its natural state can be seen in Figure 118 (*Upper Right*). The blood flows in the direction of the numbers (1) to (10). It enters the right half of the heart from the large veins of the body, and collects in a space above the valve of the ventricle. This space is known as the auricle (2). When the heart expands, the blood flows rapidly through the open valve into the right ventricle (3). From the latter it is forced by the contraction of the heart through the valve (4) into the pulmonary artery (5). The blood then flows through the lungs, gives up a portion of its carbon dioxide, and returns to the left heart by way of the pulmonary veins as light-red oxygenated blood. In the left heart the blood takes a similar course. It collects in the auricle (7), flows through the valve into the ventricle (8), and passes from the latter through the upper valves of the left heart (9) into the large arched aorta (10).

The Valves of the Heart. Of the four valves, the lower or auriculo-ventricular valves between the auricles and the ventricles [Fig. 113 (a) and (b); Fig. 118, under (2) and under (7)] are known as the tricuspid (right half of the heart) and the mitral (left half of the heart). They consist of flaps of tissue resembling sails, attached by their bases to the margins

of the auriculo-ventricular aperture. The edges of these flaps hang into the ventricle when the heart is empty. A number of stout connective-tissue cords, the chordæ tendineæ, are attached to these edges. The chordæ tendineæ are themselves fixed to muscular elevations of the ventricular wall known as the papillary muscles. These muscles are elastic and function as spiral brakes that limit the movements of the valves. The upper valves [Fig. 113 (c) and (d); Fig. 118 (4) and (9)] are known as the semi-lunar valves, because they consist of crescent-shaped pouches. Figure 118 (*Upper Right*) shows the right semi-lunar valve closed (4), while the left one is open (9).

The "Primum Oriens." While the heart contracts, no blood can flow into the ventricle. Nevertheless blood flows uninterruptedly from the body to the heart. This blood collects in front of the ventricle, thus distending the portion of the blood vessel just in front of the entrance to the ventricle. In this manner a kind of expanded antechamber, the auricle, has developed in the course of animal evolution [Fig. 118 (2) and (7)]. It functions mechanically as a reservoir into which the veins empty while the contraction of the ventricles is taking place. In higher animals the auricles have developed small accessory spaces that overhang the heart like the ears on an animal's head, whence they derive their name. The right auricle is that point in the heart which first begins to beat during embryonic development, and is the last to stop beating at death. For this reason the old anatomists called it the *primum oriens, ultimum moriens*—the first to arise, the last to die.

The Wall of the Heart. The wall of the heart consists of an ingenious interlacing of muscle fibres. As a result of the S-shaped curve of the vascular tube during the development of the heart [Fig. 24], the fibres converge in spiral courses to the cardiac apex, where they form a vortex before turning upward to their

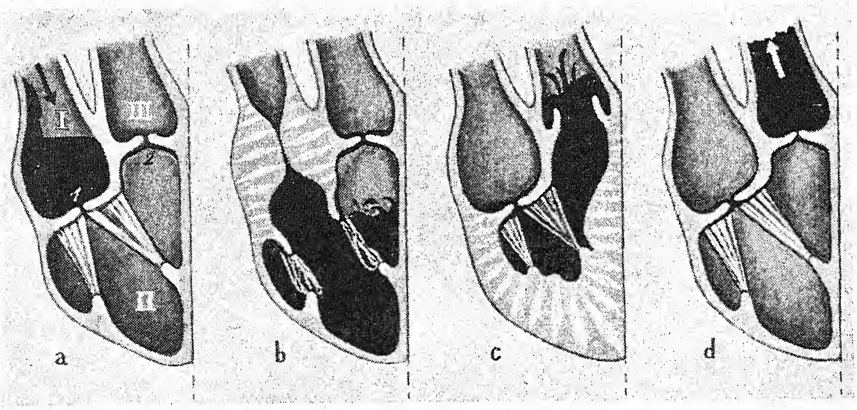


FIG. 114. *The four phases of cardiac activity. First (a) the auricle (I) of the heart is filled with blood; (b) the auricle then expels the blood through the auriculo-ventricular valve (1) into the ventricle (II); (c) the ventricle expels the blood through the semi-lunar valve (2) into the artery (III); (d) by its own weight the blood closes the semi-lunar valve behind it, and is impelled upward by the next heart-beat.*

points of attachment [Figs. 115 and 116]. The cardiac muscle fibres are the best-developed muscle fibres of the body, for they perform the heaviest work without cessation. If a longitudinal section is viewed under the microscope, one sees a beautiful mosaic arrangement, as shown at (a) in Figure 118. If the cardiac muscle fibres are subjected to a more detailed investigation, and a three-dimensional model is constructed on a basis of these studies, we have a structure like that at (b). An isolated single fibre from this structure will present an appearance like that at (c). The wall of the heart is composed of many hundreds of thousands of structures like this fibre cell.

The Coronary Vessels. Among lower animals the cardiac muscle fibres are nourished by the blood flowing through the heart. In higher animals special cardiac vessels pass from the large aorta into the musculature of the heart, surrounding every part of the heart, including the most delicate microscopic fibres (e), with a compact vascular network. Although the weight of a functioning heart is only one hundredth of the weight of the body, yet it removes from the circulation one twentieth of the blood volume for itself! The most industrious of all organs is the best nourished by the body. Because of their arrangement the blood vessels of the heart are known as the coronary vessels. They possess a positively fateful importance for the ability of the heart to perform its function.

The Pericardium. The various viscera—heart, lungs, intestines, abdominal glands, kidneys, and sex organs—do not lie free in the body

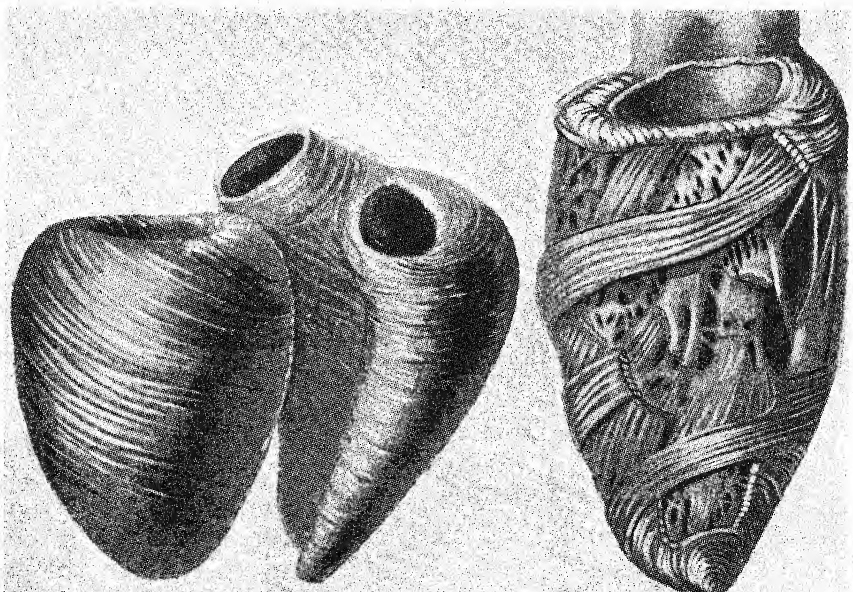


FIG. 115. *The structure of the cardiac wall. Each part of the heart is embraced by bundles of muscle fibres. These bundles run in crossed spirals, thus creating a very strong wall—imperative for the heavy, ceaseless work which the heart has to perform.*

like toys in a box, but are suspended in sheaths like the muscles. The pleura of the lungs, the peritoneum of the abdomen, and the pericardium of the heart are such suspension structures. In principle they resemble the tendon sheath in Figure 96 and the diagram in Figure 117 (b). They are double-walled sacs which form during embryonic development owing to the circumstance that the organs grow into them from without.

Double Walls

In Fig. 117 (a), (I) is a fist; (II) a rubber ball half filled with air; (III) is a table top. The fist is pushed into the ball (b) until it almost touches the table. The fist is thus surrounded by two rubber walls, and when it is moved back and forth, the two rubber walls slide past each other. In a similar manner the heart is covered by the pericardial sac (c), the lungs by the pleura, and the intestines by the peritoneum. The narrow space between the two walls of the sac contains a slight amount of fluid which serves to lubricate the surfaces. This prevents the moving heart from becoming abraded by rubbing against neighbouring organs.

The Action of the Heart. The beat of the heart is not a simple contraction like the clenching of a fist, but occurs in the form of a contraction wave which begins at the mouths of the great veins, passes over the auricles, then over the ventricles, and ends at the apex of the heart. Each beat of the human heart lasts about 0.8 second. Both valves of the heart function synchronously, the auricles contracting together and the ventricles together. In analysing the action of the heart, or the cardiac cycle, the auricles and the ventricles are each regarded as one organ. The contraction (or systole) of the auricle takes about 0.1 second, its period of relaxation or diastole about 0.7 second. The contraction of the ventricle commences when the systole of the auricle ceases, and lasts approximately 0.3 second. It then relaxes for about 0.5 second. At the end of each cardiac cycle there is a brief pause, which is followed by the next cycle. Auricle—Ventricle—Apex—Pause . . . Auricle—Ventricle—Apex—Pause: this is the rhythm of the heart action [Fig. 119]. During the short pause the heart recovers from its exertion and eliminates the fatigue substances that have collected. The heart beats about 100,000 times daily, and rests an equal num-

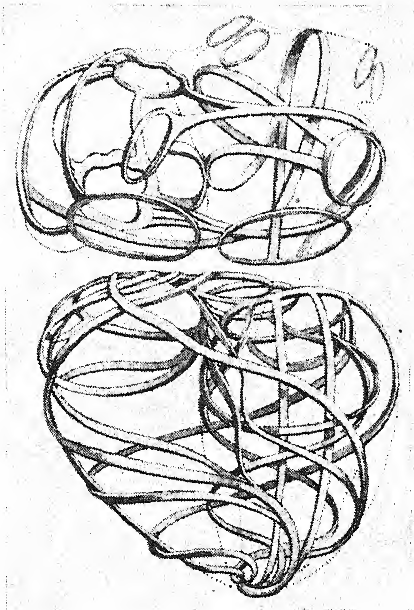


FIG. 116. *The tendons of the heart. Tough tendinous strips are woven into the muscle bundles of the heart. At the points of entry of the great vessels, these tendons form strong supporting rings for the muscular structure. Spiral arrangement of the tendons ensures great strength.*

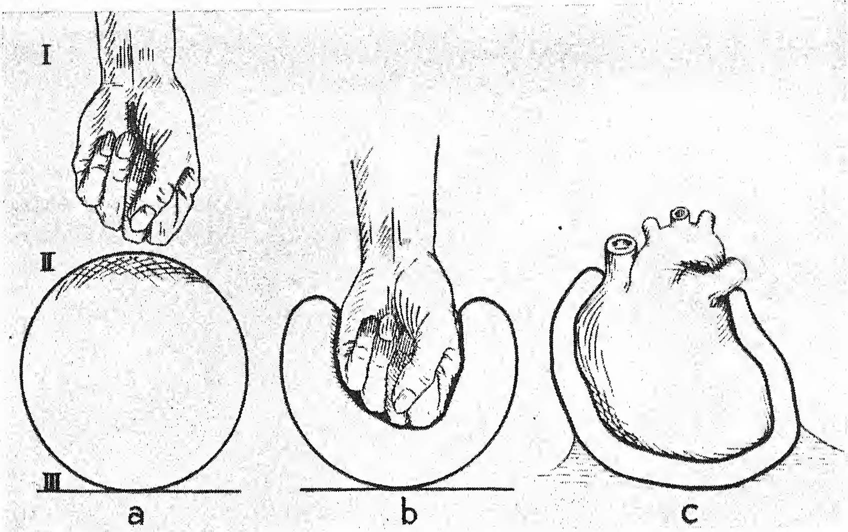


FIG. 117. *The pericardium is a double-walled sac, such as is formed when a fist is pressed into a soft, elastic ball. How the pericardium surrounds the heart is shown at (c).*

ber of times between beats. If this number be multiplied by the duration of the rest period, which is approximately $\frac{1}{16}$ of a second, we arrive at a total daily rest period of 6 hours, or a period of 20 years in the course of a lifetime. Thus our heart can stand still for 20 years—but only when this period is divided into intervals of $\frac{1}{16}$ of a second.

In the course of a year the heart beats 40,000,000 times. With each beat it discharges 6.1 to 6.7 cubic inches of blood from each ventricle. In the course of a day each ventricle pumps 10,600 quarts through the blood vessels, and in a lifetime approximately 55,000,000 gallons [Fig. 111]. In order to comprehend the magnitude of this performance let us restate it in terms of mechanical work. As defined in physics, work is measured by the weight raised multiplied by the height to which it is lifted. In calculating the mechanical work of the heart the height is replaced by the resistance presented by the blood-pressure against which the ventricles work. In the human body when at rest the resistance in the left ventricle is equivalent to that of a column of blood about 6 feet 6 inches in height, and in the right ventricle about 2 feet 7 inches. As stated above, the quantity of blood expelled from each ventricle is about $3\frac{1}{2}$ ounces. On the basis of these figures the work of the left heart would be equivalent to 1.42 foot-pounds, and of the right heart 0.56 foot-pounds. In addition to forcing a certain amount of blood into the aorta, the heart also imparts a certain velocity to the blood thus thrown out. This latter factor, however, is generally negligible and can be disregarded for small outputs.

In a human being at rest the total work of the heart per beat is roughly equivalent to 2 foot-pounds. With 70 beats per minute the heart performs a quantity of work equivalent

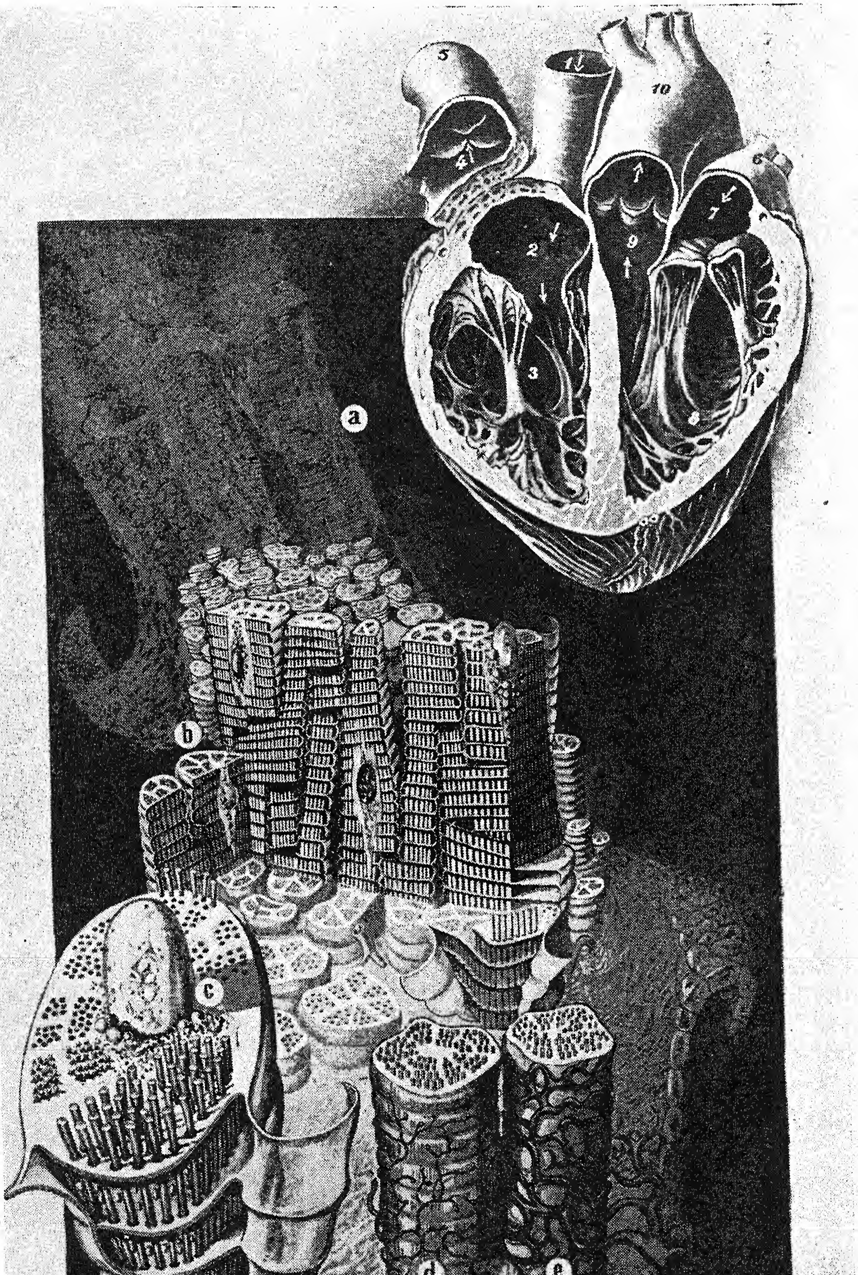


FIG. 118. *Highly magnified sections of the cardiac muscle fibres (Centre). At upper right the heart is seen laid open, revealing its inner structure. Blood flowing through the heart follows the direction of the numerals (1) to (10). (Pages 142-144.)*

to 140 foot-pounds per minute, making it an engine of 1/240 horse-power. Supposing an elevator could be driven by his heart, an individual could ride from the ground floor to the fifth storey of a house in one hour. While the human heart is not the most powerful of all motors, in its class it is beyond doubt the most capable one. For there is certainly not another machine with such a complex structure and function that can work uninterruptedly without either repairs or overhauling for a period of seventy to eighty years.

At present it is already possible to maintain a heart alive outside the body for months, by suspending it in an artificial circulation [Fig 120]. Care must be taken that the solution which supplies the heart with nutritive materials is renewed regularly and freed from the fatigue substances that accumulate. Although it has not yet been done, it is already theoretically possible to construct a small engine driven by such a heart. It would be possible to construct an engine in which not only one, but four or even eight hearts work together—a four-heart engine [Fig. 121]. Such a machine would travel about two and a half miles in an hour; in one year it could travel round the earth.

The Pulse. When the left ventricle contracts, it ejects a certain quantity of blood into the large arterial blood vessel, the aorta, which emerges from it. Since the aorta is already filled with blood, its elastic walls are forced to expand. During the pause in the action of the heart, the wall of the aorta contracts, forcing the excess blood to proceed along the circulatory system. This alternate expansion and shrinking, or pulsation, of the aorta produces a wave which passes along the entire arterial system, diminishing gradually the farther it travels from the heart. This pulsation can easily be recognized in any artery that can be felt through the skin, and is known to all of us

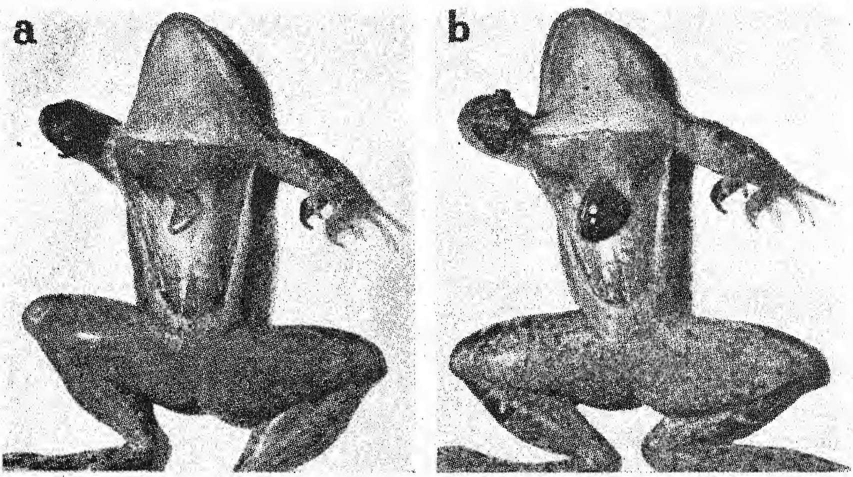


FIG. 119. *The functioning of the heart, illustrated by that of a frog. At (a) the heart has contracted, expelling the blood; at (b) it has dilated, drawing in fresh blood.*

as the pulse. It is generally felt by placing a finger on the under surface of the wrist on the side of the thumb, where the radial artery is located [Fig. 122]. Since it depends on the contraction of the heart, an examination of the pulse yields information about the heart rate and the state of the pressure within the circulatory system. The pulse rate depends on the blood requirements of the body. Small bodies lose more heat than large ones and consequently require a more rapid circulation of the warming blood. The pulse rate in small birds is almost 200, in cats 130, in man 75, in the horse 35, and in an animal which is not only large, but also thick-skinned, such as the elephant, it is only 25. The heart of a newborn beats twice as fast as that of an adult. The pulse rate is most strongly influenced by work. At any particular time the normal heart pumps enough blood through the circulatory system to satisfy the oxygen requirements of the body.

The Heart's Rhythm

Figure 125 shows the dependence of the pulse rate on various states of the body. In itself it is a matter of no importance whether an individual has a pulse of 60 or 80 when at rest. It is the functional capacity of the heart that is the decisive factor.

Is the Heart an Automobile? If one opens a hen's egg after twenty-six hours of incubation, the mass of cells from which the chick's heart develops can be seen beating when viewed with a magnifying glass. The heart beats before it is even a heart! No one should miss seeing this remarkable phenomenon, which was discovered by Aristotle and has been named *punctum saliens,* the "springing-point." If the primitive heart-mass is removed from the egg and placed in a warm nutritive medium, the cells continue to grow. If the growing heart is cut into six pieces, each piece continues to contract for some time. Is the heart a self-moving apparatus, an automobile? This is one of the most interesting problems of biology, but all we can say is that the heart possesses as a physiological characteristic an automatic rhythm.

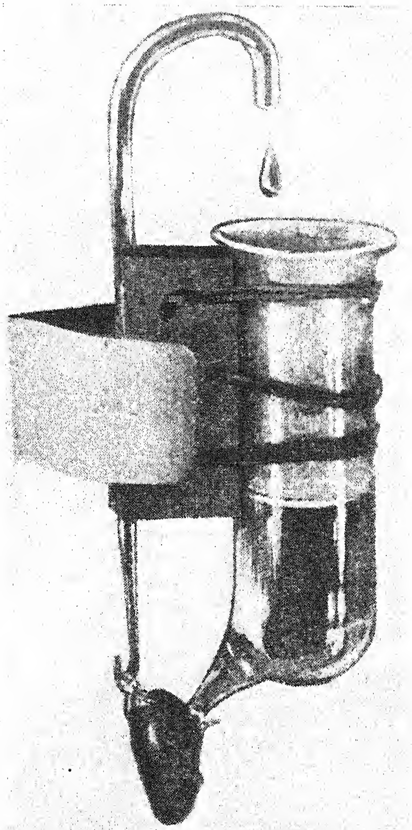


FIG. 120. *An isolated heart, removed from an animal body, yet still beating, because it is supplied with a nutritive solution by artificial means.*

The Motor of the Heart. It has already been stated that the beat of

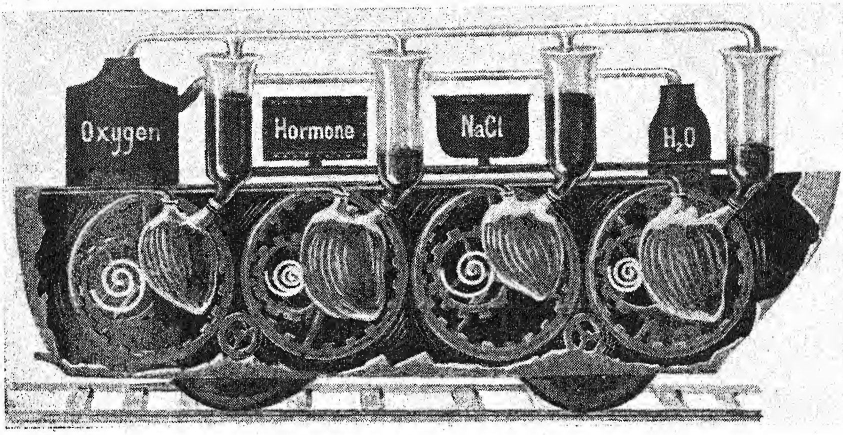


FIG. 121. *The human heart develops approximately 1/240 horse-power. In theory, it is possible to construct an engine driven by isolated living hearts, artificially nourished.*

the heart takes its origin at the mouths of the great veins in the right auricle, whence it spreads over the rest of the heart. The beat of the heart originates in a small but characteristic mass of cells located near the great veins in the right auricle, and known as the sino-auricular node [Fig. 268 (c)]. Another similar mass of cells is to be found in the wall separating the right and left auricles, and is called the auriculo-ventricular node. From this structure a band of fibres passes to the walls of the ventricles [Fig. 268 (d), (e)]. Since the impulse to contract originates in the sino-auricular node, it is known as the pace-maker of the heart. From this point the contractile impulse is carried to the other parts of the heart by the system of fibres described above.

The Automatic Regulation of Cardiac Tempo. The rate of the heart action is regulated by the carbon dioxide content of the blood. In the wall of the right auricle there are " disk signals " that react to the presence of carbon dioxide molecules by adjusting the rate of the heart-beat to the carbon dioxide content of the blood. If a muscle functions somewhere in the body and produces carbon dioxide, the carbon dioxide molecules are carried to the signal disks of the heart ten seconds later, increasing the rapidity of the heart-beat. If the muscle stops working and the carbon dioxide content of the blood is decreased, the action of the heart becomes slower—an extremely simple and expedient arrangement. The heart is a pump which is automatically regulated by the carbon dioxide content of the circulating fluid.

The Cardiac Nerves. In order that cardiac activity may be adapted to the requirements of the body as a whole, its automatic mechanism must be subject to the central nervous system. This subjection is effected by means of nerve fibres connecting the heart with the central nervous system. The effect of these fibres is either to increase or to diminish the activity of the heart, depending on the needs of the body in a particular situation.

The most important of these

nerves are the tonus nerves that regulate the state of tension of the cardiac wall, as well as two antagonistic nerves, of which one accelerates the action of the heart while the other inhibits it. The accelerating nerve is called the sympathetic; the inhibitory nerve is known as the vagus. All mental excitation is connected with a stimulation of the sympathetic nerve. It is on this account that the heart beats more rapidly when one is excited. All depressing events stimulate the vagus, thus inhibiting the action of the heart, so that it seems to stand still because of fear, fright, or sorrow. Both nerves can be stimulated at various points. By exerting pressure on the eyeball, the vagus is stimulated, and the pulse rate is decreased. The vagus can also be stimulated by pressure over the vertebral column in the neck because it passes downward more or less parallel to the vertebral column.

But, unlike the vagus, the sympathetic is not superficially located, but runs downward in the deeper layers of the neck right alongside the bodies of the spinal vertebræ into the thorax. If there is an enlarged organ in the neck, such as a goitrous thyroid gland, or a tumour which presses upon the sympathetic, the rate of the heart-beat is increased. The sympathetic and vagus have rightly been described as the whip and the reins of the heart. In the body the heart runs like a horse harnessed to a wagon. The sympathetic nerve is the whip with which the horse is driven on; the vagus is the analogue of the reins with which the horse is curbed.

An ordinary mortal cannot influence his heart-beat voluntarily, because the centres from which the vagus and the sympathetic take their origin lie deep under the cortex of the brain, the seat of conscious volition, and there are no direct connecting fibres between them. At least not in present-day man.

The sensory and motor areas of the cerebral cortex occupy only a small part of the entire structure. The

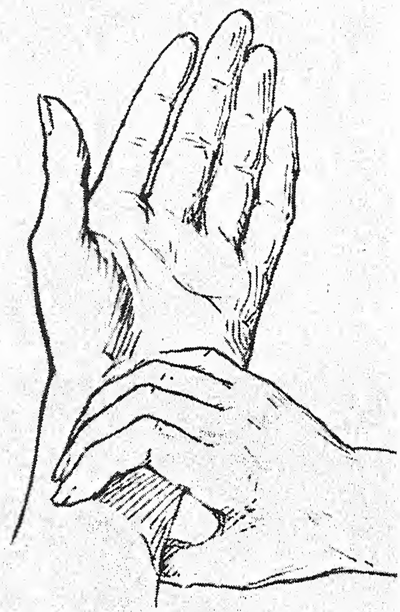


FIG. 122. *Feeling the pulse—not with one finger, but with the tips of several fingers.*

greatest part of the frontal lobes as well as large areas of the parietal and temporal lobes are not concerned with the immediate reception or transmission of nerve impulses. These areas are richly supplied with interconnecting nerve cells and fibres, and are assumed without very positive proof to be the seat of the association function of the brain.

Each creature has as many association or connecting fibres as it has acquired, either in the course of the

development of its species or during its individual life. We receive the historically acquired connecting fibres as an inheritance from our ancestors; we must "acquire" the others ourselves in the course of our lives. At birth an infant's brain may be compared to a clean page as far as associative impressions are concerned. The activities which the infant exhibits are reflex. As it grows, however, sense impressions begin to come into the sensory areas of the cerebral cortex. In some as yet unknown manner these effect changes, thus registering more or less definitely as memories. After a while the child possesses a considerable number of such impressions. When in the child's mind these independent impressions are connected to form a whole, we speak of an act of association.

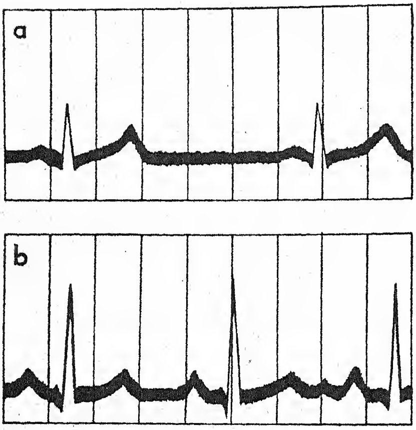


FIG. 123. *The electrocardiogram records the action of the heart. That at (a) is the typical curve produced by a healthy heart; at (b) the curve of a diseased heart.*

Such acts of association are supposed to be carried on within the association areas of the cerebral cortex by means of the connecting or association fibres. The increase in intellectual power accompanying the growth of an individual is not due to any increase in the number of nerve cells, for the child is born with his full number. It is based, instead, upon their continuous development, consisting chiefly in more and more branching, with correspondingly richer connections.

Controlling the Heart

The association areas in the cortex reach their highest point of development at about the thirty-fifth year, when the paths of association have been laid down. This does not mean, however, that all possible associations have been formed. They continue to be formed so long as the brain continues active. Repetition of similar impressions in the course of individual experience strengthens such associations until functional relations are established between certain activities and psychological states. This is what is meant when we say an individual learns something. However, just as he learns to read, write, calculate, or play the violin, he can also learn to control his heart. Among many other things, the fakirs of India also practise to control the action of the heart, and learn to do this to such a degree that they can bring the heart to a standstill of their own volition.

Simulating Death

Occasionally this ability is likewise present in individuals who are not Indian ascetics. While lecturing, the physiologist, Weber, demonstrated this experiment to his students. On one occasion he carried it so far that he fainted. In the presence of a number of physicians, among whom was the famous Cheyne, Colonel Towns-

end, an Englishman, lay down on the ground, let his heart stand still, and continued to lie as pulseless as a corpse for a half-hour, so that those present believed he had died. Just as they were about to leave the supposedly dead man, his pulse-beat and respiration returned. A celebrated Egyptian physician and fakir, Tahra Bey, could not only increase his heart rate to 180, but also raise his body temperature to 110° at the same time.

The Heart Sounds. At night on going to bed lie flat on your back. You will then hear the beating of the heart. Two sounds can be distinguished: the first is low-pitched, strong, and prolonged; the second is of higher pitch, shorter, and sharper in character. The sounds may be compared to syllables: *lubb, dúp* . . . *lubb, dúp*. . . . The first sound is a muscle tone, probably caused by the vibrations set up by the contraction of the thick muscular wall of the ventricle; the second sound is due to the closure of the semi-lunar valves.

Just as an engineer can estimate the condition of a machine at a particular time by the sounds which it produces when in action, similarly an experienced physician can obtain important information regarding the condition of the heart by paying close attention to the rhythm, character, and distribution of the heart sounds. This is a difficult art, which can only be acquired as a result of a great deal of practice.

The Electrocardiogram. Like every other muscle, the heart in contracting gives rise to an electrical "action" current, which can be led off and transferred to a strip of film [Fig. 123 (a) and (b)]. The curve thus obtained is called an electrocardiogram. On the basis of this electrocardiogram the condition of the heart can be determined with great precision. If the auricles are overburdened peak 1 is heightened: if the ventricles are encumbered peak 2 is higher; when the heart muscle is diseased, peak 3 may be broadened, and so on. Figure 124 shows the electrocardiograms of two dying hearts. Heart (a) is the type of heart that " rides itself to death," as in febrile diseases. The tracing reproduces the moment at which normal cardiac activity ceases. The first part of the tracing exhibits a certain lack of clarity, but is still essentially normal. Then the normal rhythmic functioning of the heart disappears and is replaced by an entirely irregular fibrillation with 240 beats per minute. This heart resembles a horse which runs away, racing madly, until it collapses and dies in convulsions. Heart (b) is the

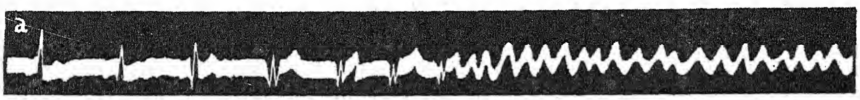
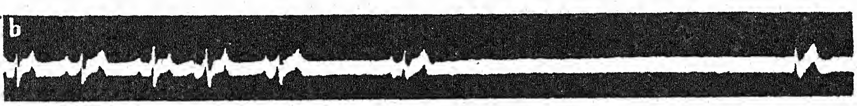


FIG. 124. *The death of the human heart, revealed by electrocardiogram. At (a) irregular fluctuation, typical of fever, replaces normal rhythm; (b) shows the final collapse of a tired heart. When the heart-beats cease, the graph becomes a straight line.*



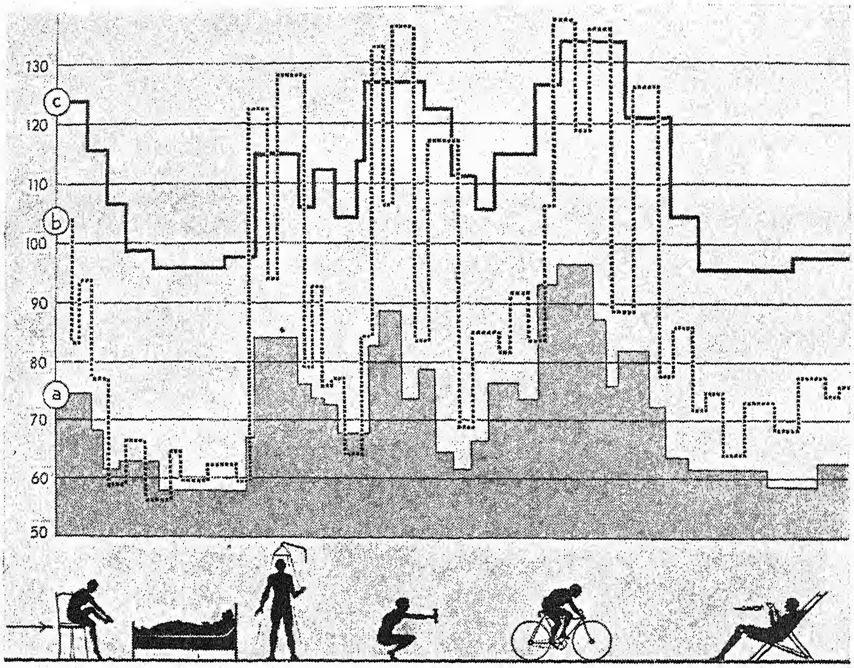


FIG. 125. *Here six forms of human activity are represented, while above are graphs of the resulting pulse rates associated with three characteristic types of heart (a, b and c). The healthy heart (a) adapts itself to the varying demands made upon it, and the pulse rate returns speedily to normal. The graph of the nervous heart (b) exhibits wide fluctuations at all times, even during sleep, while the pulse rate of a diseased heart (c) is constantly higher than normal, even in the absence of all bodily exertion.*

type of heart which grows weary without "revolting." The heart action simply becomes weaker, the peaks of the electrocardiogram become lower and blunter, and the intervals between beats grow longer. Finally the last beat is followed by the straight line indicating the complete standstill which leads to eternity.

The Nervous Heart. The nervous heart is a heart which is organically healthy but reacts pathologically to nervous stimuli. An individual with a nervous heart may perhaps suffer more than a person with a serious degeneration of the cardiac muscle, but his heart is not sick; it is simply "nervous." A sick heart is like a motor car with a defective motor. A nervous heart resembles a motor car with an excited chauffeur. The car is in good shape, but it is not driven well. The pulse curves of three hearts have been superimposed in Figure 125. The healthy heart (a) adapts itself to the required tasks by an appropriate increase of the pulse rate and returns rapidly to its normal level. The pulse rate of the sick heart (c) is constantly increased, even during sleep! Exertion does not increase its pulse rate by 20 beats, as in the normal heart, but by 40, and it recovers slowly. The curve of the nervous heart (b) fluctuates

pathologically—even when at rest! Exertion causes the pulse rate to increase very rapidly and to return to its normal level with extreme rapidity. These steep peaks are already indicative of nervous and not organic disturbances. However, the curve obtained during sleep is decisive. The curve of the sick heart remains at a high level even during sleep. The curve of the nervous heart returns to the level of the normal heart when all external and internal nervous stimuli are excluded, but nevertheless continues to fluctuate restlessly. The fall of the pulse rate during sleep is a definite symptom of the nervous nature of a heart malady.

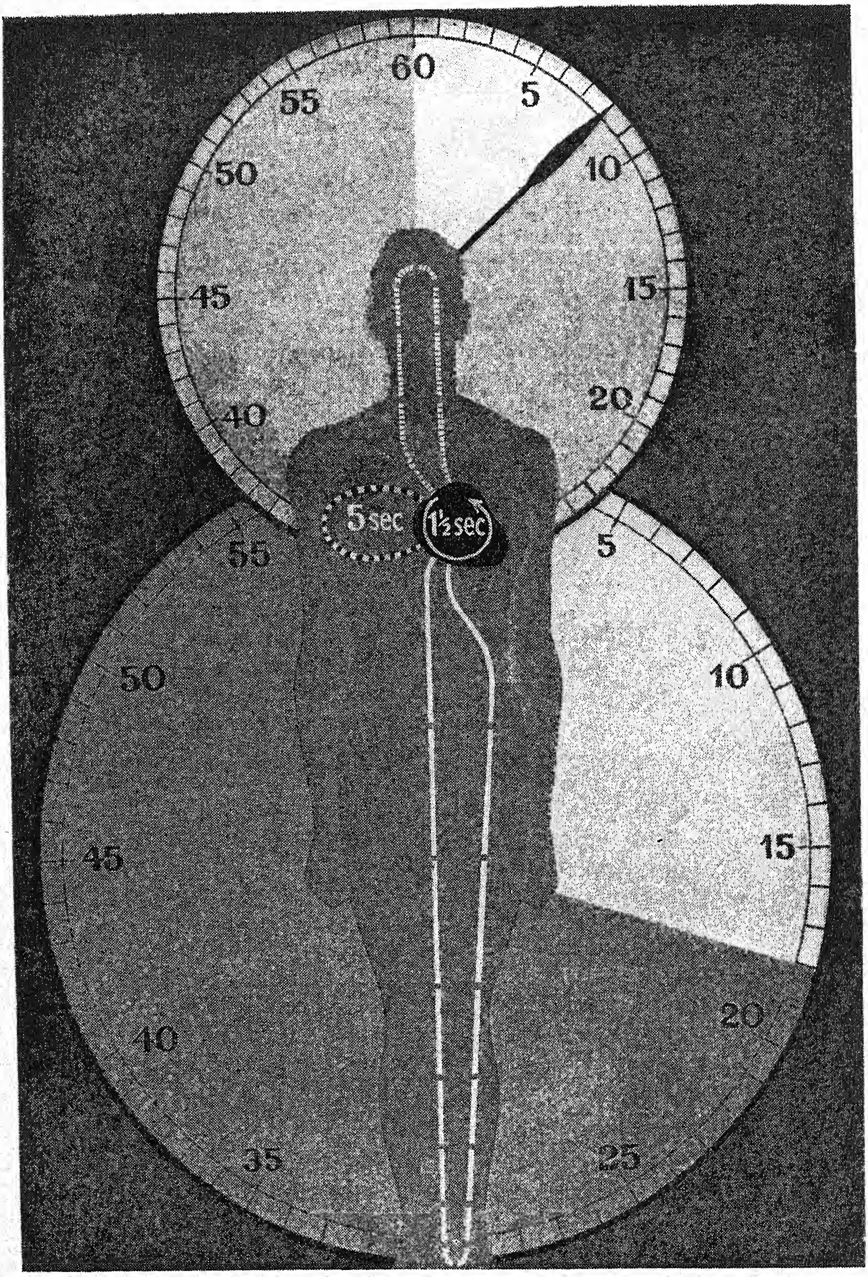
Cardiac Neurosis

A large number of those people with so-called " heart trouble " really have no disease of the heart, but are —sick of life. In an overwhelming number of cases a cardiac neurosis is the expression of some emotional disturbance. The wide variety of individuals affected with cardiac neuroses is astonishing. The patient may be a young girl with a prettier younger sister, an official who is not receiving the promotion he believes due to him, or a typist envious of the beautiful women in the motion picture magazines. Cardiac neuroses are also met with among the numerous individuals affected by unfortunate experiences during childhood, either at home or in school, among those affected by some form of fear—fear of failure in professional or business life, fear of losing a job, business losses, disease, age, etc.—as well as among women who are unsatisfied or have been disillusioned in their sex life or personal ambition. The affected individuals need not even be conscious of these internal dissatisfactions and fears.

Treatment of Neurosis

Indeed, it is those people who are not conscious of them and would emphatically deny such motivations into some dark corner of whose hearts have crept fear, ambition, and the desire to be interesting, there to carry on their gnawing activities.

This neurosis is not a disease, but an affliction. No one dies of a cardiac neurosis, but the afflicted individual continues to suffer until the hidden cause is removed, or until old age comes to remove the affliction together with the desires and passions that cause it. Medicaments are of little avail; much more efficacious is treatment by a physician who knows human nature, and how to guide the actions of human beings along the right channels. To be sure, this type of treatment is more difficult than the routine prescribing of sedatives.



HOW FAST DOES OUR BLOOD FLOW?

FIG. 126. *Blood traverses the heart in 1½ seconds, the lesser circulation in 5 seconds. It goes from heart to brain and back again in 8, to the foot and back in 18, seconds.*

CHAPTER XI

The Blood Vessels

THE STRUCTURE OF THE ARTERIES. THE CAPILLARIES. VASCULAR NEUROSIS. THE VEINS. VARICOSE VEINS. THE VASOMOTOR NERVES. VASOMOTOR TONUS AND CEREBRAL ACTIVITY. SHOCK. KNOCKOUT. BLOOD-PRESSURE. HARDENING OF THE ARTERIES.

THE vessels through which the blood is pumped out of the heart to all parts of the body are known as arteries. They must withstand the powerful pressure of the blood, and consequently have an extremely strong wall. The large vessels close to the heart can withstand a pressure of 20 atmospheres! Essentially an artery is a muscle tube, consisting of fibre bundles disposed circularly round the vessel [Fig. 127 (a)].

Elastic Fibres

These muscle fibres are reinforced with alternate layers of connective tissue (b). In the larger arteries elastic fibres unite to form layers (c and d) which alternate with the muscle fibres. These layers are connected with one another by means of elastic fibres which pass between the muscle bundles. The elastic tissue is particularly abundant towards the outer and inner surfaces of the vessel, where it is described as forming special layers that pull the artery together like taut rubber bands. In order to prevent the blood from rubbing against the folds on its inner surface, the inside of the tube is covered with a layer of flat cells (e). The outer surface of the artery is covered by loose connective tissue (f), which cushions the impact of the forward, projectile motion of the pulse. Small accessory blood and lymph-vessels (g), which supply the cells of the arterial wall with nutrient materials, pass through this padding. Each artery has its private arteries, the "vasa vasorum." In addition, the arterial wall is plentifully supplied with an intricate system of nerves that regulate the width of the vessel [Fig. 130]. An artery is not an inanimate object like a rubber tube, but an organ which participates actively in the life of the body, and whose function is of fateful significance for the activity and well-being of the body.

The Capillaries. In their course through the body away from the heart the arteries undergo extensive ramification, terminating in minute vessels. The functional principle underlying this system of ramification may be stated as follows: When an artery divides, the combined area of its branches is greater than that of the trunk from which they arise in the first place.

Hair-like Vessels

The farther it proceeds from the heart, the wider is the channel of the arterial system and the broader the blood-stream, so that the rate of flow becomes proportionately slower. At the same time the blood-pressure falls, and the arterial wall becomes

thinner. The minutest branches are hair-like vessels called capillaries. They are fifty times thinner than the thinnest human hair. The average diameter of a capillary vessel is about 1/3,000 inch, so that the blood corpuscles usually pass through it in single file. About seven hundred capillaries could be packed into the space occupied by the shaft of a pin. The number of blood vessels in the body is immeasurable and surpasses any power of imagination. On examining his first preparations, the Dutchman, van Hoorne, who had invented a method of rendering the blood vessels visible by injecting them with a red substance, was so amazed that he exclaimed: "The body consists only of blood vessels!" But at most he saw only about one quarter of the blood vessels actually present in the body [Fig. 128]. Peter the Great, then visiting Holland to acquire the culture of the West for his Eastern empire, was so delighted with these specimens that he bought them. On their arrival in Russia, however, they were found to be spoiled; during the journey the sailors had consumed the alcohol in which the specimens were preserved.

Vital Second

As the vascular system becomes more capacious from the large arterial vessels to the capillaries, the rate of flow in it becomes proportionately slower, until it reaches a minimum in the capillaries. Each capillary is about 1/50 of an inch long. If all the capillaries in the human body were placed end to end we would have a tube passing four times around the earth! While passing around the body, a quantity of blood takes about one second to flow through the 1/50-inch capillary. During this second when it passes through the capillary the blood performs its nutritive and metabolic function. The blood does not leave the blood vessel, however. It flows within the closed circulatory system; but the wall of the capillary is extremely thin, consisting of only a single layer of cells. Through this wall the blood gives up its oxygen to the surrounding tissues and receives their carbon dioxide. At the same time other nutritive substances also pass from the blood to the tissues, while waste products are received by the blood-stream. With this the blood has fulfilled its function and returns to the heart.

Two Circulations

A capillary generally forms a loop uniting with adjoining capillaries to form vessels of greater diameter. These vascular tubes, or veins, bring the blood back to the heart [Fig. 126]. The blood is carried away from the heart by the arteries and distributed throughout the body. It is most widely distributed in the capillaries, whence it is returned to the heart by way of the veins. Attached to the greater or systemic circulation, which carries the blood throughout the body, is the lesser circulation, which transports the blood through the lungs. The blood vessels also ramify in the lungs until they form capillaries through whose walls the exchange of the respiratory gases takes place. This exchange occupies approximately 1 second. The entire circulation of the blood takes place with astonishing rapidity [Fig. 126]. The time taken by a portion of the blood to pass through the heart is about 1.5 seconds, through the lesser circulation (heart-lung-heart) about 5 to 7 seconds. The time required

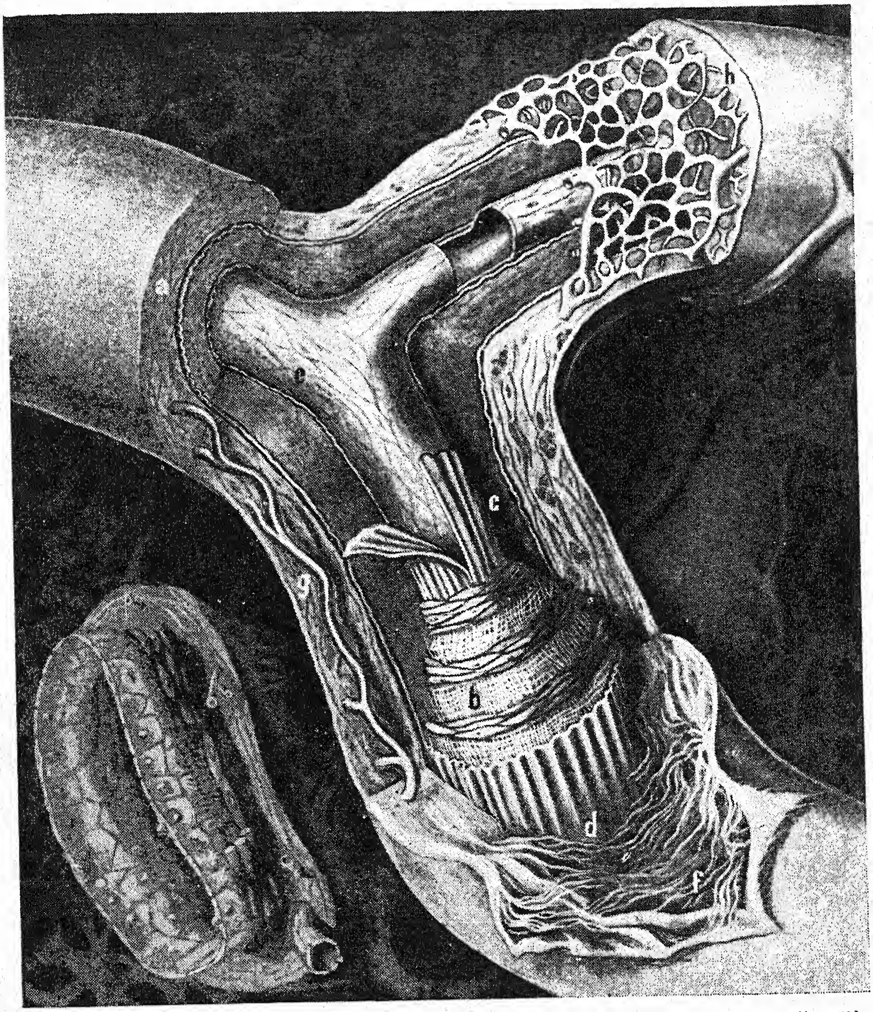


FIG. 127. *The larger drawing above shows the structure of the arterial wall. The strength and elasticity of this complex muscular organ are vitally important for our life and health. At lower left can be seen the more simply constructed wall of a vein.*

for passage through the greater circulation depends on the path taken by the portion of the blood. The circulatory system is made up of a large number of vessels varying widely in length so that the actual time taken by a drop of blood varies greatly. Each time it may take a different path. One twentieth of the blood flows from the aorta into the cardiac arteries and passes through the substance of the heart. This short trip is made very rapidly, in 3 to 4 seconds. Blood flowing to the brain returns in 8 seconds. Blood passing through the trunk and the legs to the toes requires 18 seconds for the double trip. The time required for the blood to

circulate through the entire body—that is, the greater and lesser circulations (heart-lung-heart-body-heart)—is about 23 seconds. If the number of heart-beats and the pulse rate are increased under the influence of fever or work, the blood flows twice as fast. In the course of a day a blood cell makes about 3,000 round trips through the circulation.

Vascular Neurosis. There is a class of individuals who are described as vaso-neurotic, meaning that they have nervous blood vessels. Their capillaries react too violently to stimuli, like the heart in people with cardiac neuroses. The colour of their skin changes rapidly; they blush at the slightest compliment or criticism. They sneeze in the slightest draught, suffer from migraine (contraction of the cerebral capillaries) when the weather changes, and have frequent colds. They have frequent attacks of diarrhœa and abdominal cramps, and have an extremely delicate skin. If the skin on the back or chest of such an individual is stroked with a fingernail a red streak appears which remains evident for several minutes. In some subjects a definite weal results at such points, owing to the abnormal nervous state of their capillaries, which dilate too readily.

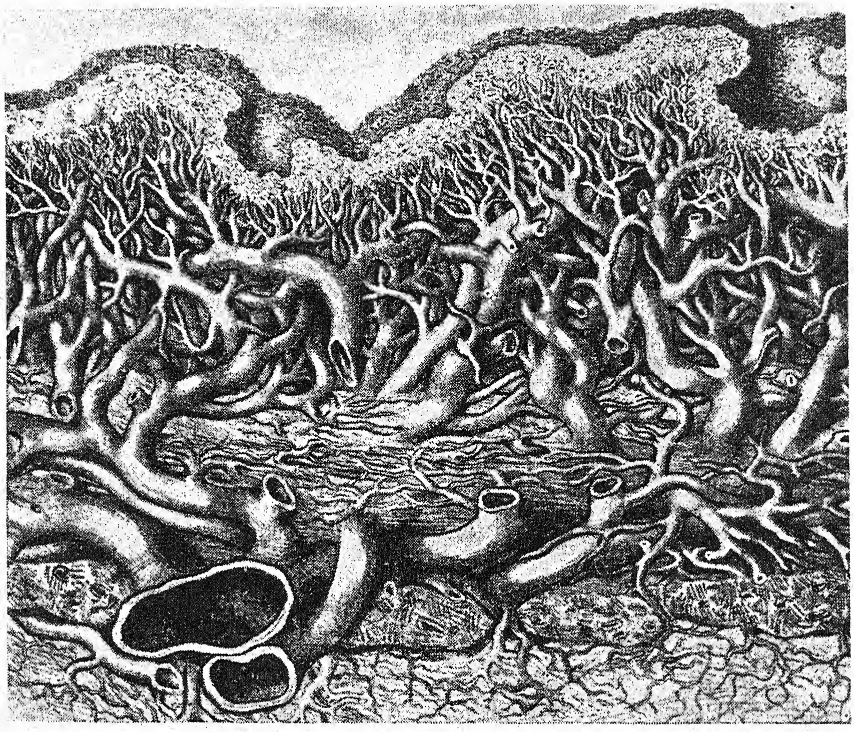


FIG. 128. *"The body is composed of blood vessels!" declared the Dutch physiologist van Hoorne in 1690. Here, greatly magnified, are seen the blood vessels contained in a minute section of the stomach wall. The entire body is permeated with blood vessels in this fashion. Their total number is beyond calculation.*

The Veins. In the veins, which carry the blood back to the heart, there is a constant decrease of pressure as the blood flows from the periphery of the body to the heart. The pressure in the great veins near the heart is generally negative owing to the aspiration of the thorax. During inspiration this diminished pressure is still further decreased. In consequence the veins are thin-walled.

One-way Track

To prevent blood in the veins from flowing away from the heart under the influence of gravity, valves are placed in these vessels which allow the passage of blood only towards the heart. Fig. 127 (*Left*) shows the structure of the wall of a vein.

Varicose Veins. The superficial veins of the lower extremities bear a heavier burden than any other veins in the body, because they carry a long and heavy column of blood extending almost perpendiculary from the sole of the foot to the heart. In persons with weak connective tissue the valves and the walls of the superficial veins yield to this pressure, the valves become incompetent, the blood ceases to flow toward the heart and stagnates in the veins. Indeed, it may even flow in a retrograde direction. The veins are transformed into sinuous, nodular tubes with wide sacculations and are known as varicose veins. When the blood stagnates the circulation is impaired, the surrounding tissues are damaged by the waste products that collect in the area, the skin above the veins begins to itch, becomes discoloured, and often breaks down so that ulcers are produced.

The best remedy against varicose veins is prevention. Anyone who has weak connective tissue should not choose an occupation in which he must be on his feet continuously for hours. He should not become a baker, tram-driver, conductor, postman, or laundry worker. If early signs of varicose veins appear, the connective tissue and muscle fibres of the skin and blood vessels should be strengthened by means of gymnastic exercises. The foot end of the bed is raised and the individual lifts a ten-pound weight with his affected leg; later the weight is increased to as much as thirty pounds. At night the foot end of the bed should remain slightly raised. If the skin appears to be damaged, a physician should be consulted as soon as possible. Some cases can be helped by means of elastic bandages; in others it is necessary to inject the veins, or to remove them surgically. Only a physician can decide what steps must be taken in a particular case.

Regulating Blood-flow

The Vasomotor Nerves. All the blood vessels of the body are supplied with an intricate network of nerves, known as the vasomotor nerves because they govern the contraction and dilatation of the blood vessels [Fig. 130]. Each muscle fibre of a vascular wall is connected to the nervous system. Although the capillaries are also abundantly supplied with nerve fibres, they are to a large extent independently contractile; but they contract and relax in harmony with the rest of the vascular system.

In the arteries the muscle fibres are in a state of tonic contraction. It is the function of the vasomotor nerves to increase or decrease this tonus. Since the body has just sufficient blood to supply its needs, this vasomotor mechanism

furnishes a means whereby organs or regions of the body can be supplied with greater or lesser quantities of blood as their activities require. The blood vessels of the body resemble the streets of a city. They are always present, but they are by no means always filled with people. Like the majority of streets, most of the blood vessels, too, are generally only partly filled. An ingenious system of locks takes care of the opening and dilatation of the vessels. It has been calculated that at any particular time approximately only one tenth of the vascular bed present in the body is opened to the blood-stream.

Vasomotor Tonus and Cerebral Activity. After a heavy meal the greater part of the blood flows to the digestive organs in the abdomen. The brain becomes anæmic—and as a result the individual becomes sleepy. *Plenus venter non studet libenter!*—a full stomach does not like to study. Similarly, the muscles also receive less blood. Thus when an organ or group of organs is at work the tonus of the blood vessels is decreased and they become dilated.

When Bathing is Unwise

Meanwhile, all other blood vessels are relatively contracted. Such arrangements regulate the distribution of the blood to the various parts of the body. The work of regulation is performed by the constricting and dilating vasomotor nerves under the control of two centres in the medulla oblongata of the brain.

In view of these facts it can easily be seen why one should not go swimming or take a hot bath after a heavy meal. In swimming the skin and the muscles need all the blood they can get. If the abdominal organs require a large quantity of blood at the same time, there will not be enough to supply the needs of the heart, lungs, and brain, and the individual will faint. Similarly, a hot bath dilates the vessels of the skin, so that the heart has not enough blood and energy to supply two such large areas as the skin and the abdominal organs with blood at the same time.

Demand and Supply

Normally the vasomotor nerves regulate the distribution of the blood in the body very well. By means of a changing arrangement of the locks, each organ receives as much blood as it needs. The vasomotor centre, located in the brain, is connected with the other cerebral centres, and automatically functions in conjunction with them. Look at Figure 131. Is 12 × 13 actually 156? We verify it by mental calculation. At the same moment when we begin to calculate, the blood begins to flow faster through the cerebral vessels, and flows from the abdominal area to the brain. Now let us look at the lemon in Figure 131 and imagine that we have to bite into it. At this thought our digestive glands begin to manufacture a secretion to dilute the sour lemon juice that will soon enter the stomach. The vessels of the salivary glands, stomach, liver, and pancreas all dilate and become filled with blood. If the body is overheated, the vasomotor nerves open the blood vessels of the skin, and we become red and perspire in order to give off heat.

Shock. If the tension of the capillary walls is decreased, leading to a dilatation of the capillaries and a stagnation of the blood in these vessels, the affected individual goes into a state of collapse known as shock. This condition is found especially

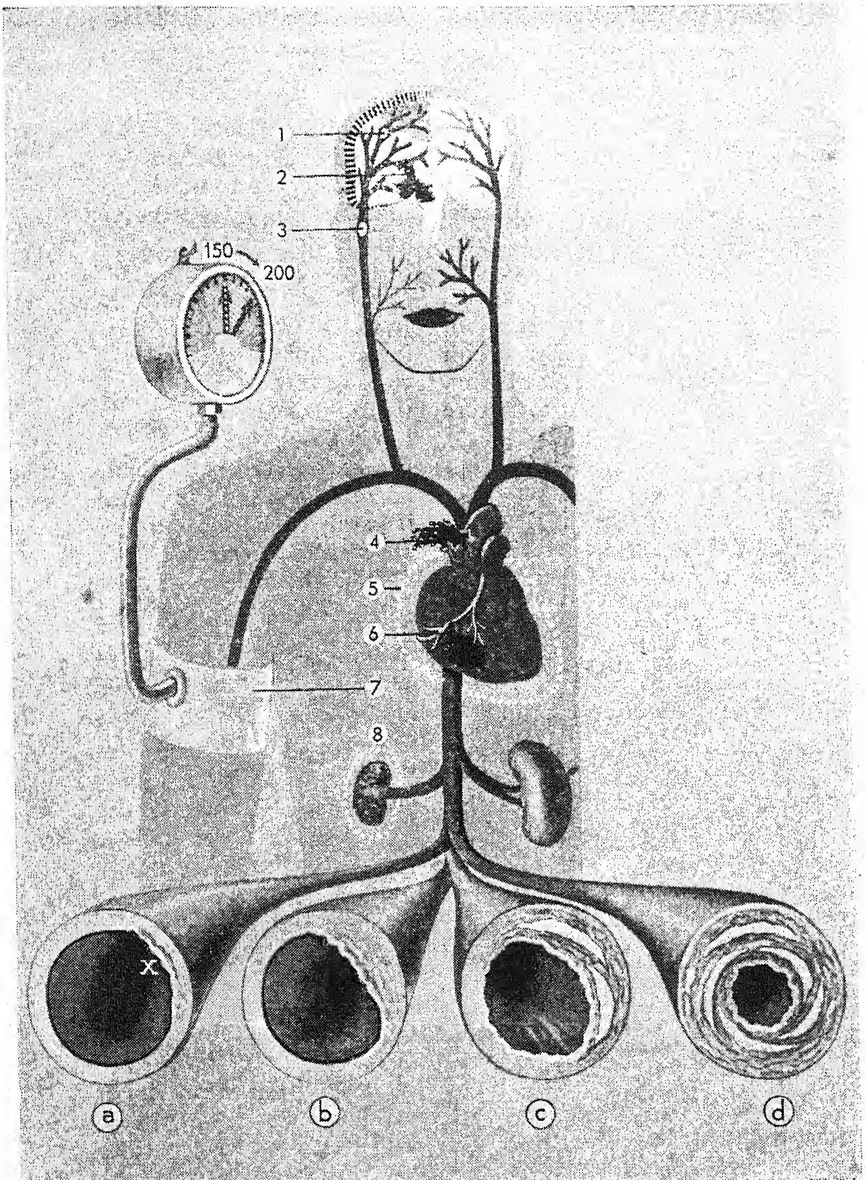


FIG. 129. *Changes in the arterial wall which end in calcification: (a) ulceration of the internal vascular wall; (b) proliferation of connective tissue; (c) deposition of calcium; (d) calcification and occlusion of the vessel (Pages 165-167). Frequent pathological consequences of such changes: (1) cerebral thrombosis; (2) cerebral hæmorrhage; (3) cerebral embolism; (4) rupture of a blood vessel near the heart; (5) dilatation of the heart; (6) rupture of a coronary artery; (7) hypertension; (8) contracted kidney.*

after severe tissue laceration, in particular of the muscles. As a result of the dilatation of the capillaries their walls become permeable, causing a constant leak of blood fluid from the general circulation into the surrounding tissues. Consequently there is an ever-lessening volume of blood in circulation and a continually increasing fall of blood-pressure. The circulation becomes inadequate, so that the heart, lungs, and brain are insufficiently supplied with blood. In treating such a condition the physician endeavours to restore the circulation.

Shock from Poisons

It has been suggested that the cause of shock is the liberation by the lacerated tissues of a substance known as histamine. It is known that this substance is a capillary dilator, and when injected into the circulation produces effects closely resembling those observed when shock supervenes as a consequence of tissue-destruction.

The vasomotor control of the blood-supply may also be affected by various poisons. Vasomotor collapse occurs in the course of severe cases of infectious disease, mushroom poisoning, and snake-bite. In these cases the vasomotor centre of the brain is paralysed by the poisons. A form of vasomotor collapse well known to all of us is the knockout in boxing.

Knockout. If a boxer is struck by a powerful blow to the jaw, his head is snapped back and his jaw is pressed against the medulla oblongata, situated where the brain passes into the spinal cord at the top of the neck. The centre for the vascular nerves is located there. This sudden shock inhibits the function of the vasomotor centre, the abdominal blood vessels dilate, the blood from the heart, lungs, and brain flows into the abdominal area, and the boxer falls unconscious to the floor. The same effect is obtained by a blow against the solar plexus, the "peripheral switchboard" of the vascular nerves within the abdomen. This may occur when a blow is struck at the level of the stomach. The stomach is a hollow ball filled with air. When struck it may burst, but this is rarely the case, since a boxer generally enters the ring with an empty stomach. Behind the stomach lies the solar plexus, the centre for the vascular nerves of the abdomen. The plexus is paralysed by the blow. There is a general dilatation of all the abdominal blood vessels, and a resultant fall in blood-pressure. The heart, lungs, and brain become anæmic, the cerebral circulation is decreased to such an extent that consciousness can no longer be maintained, and the individual collapses like a rag doll. The ill-effect of such a blow may persist so long that the individual remains unconscious until the heart simply stops beating owing to a lack of blood, and the victim dies.

A Blow on the Neck

In the neck the vagus and the sympathetic pass downwards close to the spinal column, where they form the carotid plexus. If this plexus is struck by a blow, the action of the heart is inhibited and the affected person falls down unconscious.

Blood-Pressure. For clinical purposes it is often important to determine, even if only approximately, the arterial blood-pressure in man. To do this the upper arm is enclosed in a hollow cuff of rubber which is inflated so that it exerts an equal

pressure on all sides of the arm. Air is forced into the cuff until the brachial pulse in the elbow disappears. The pressure is determined by means of a manometer attached to the cuff [Fig. 129 (7)]. This pressure is known as the blood-pressure. Since the vascular walls, like all other tissues, become harder in the course of life, a constantly greater force becomes necessary to compress them; the blood-pressure—that is, the resistance of the arterial wall—increases.

It is useless for the layman to pay any unnecessary attention to his blood-pressure. High blood-pressure is like baldness—some unlucky people get it and others do not. There are families in which the members have a tendency to high blood-pressure. If one belongs to such a family, the chances that one will develop hypertension are greater. Slight deviations from the normal blood-pressure level at a particular age are of little significance. As long as there is no pathological increase, the blood-pressure furnishes no standard by which to estimate the physical ability of an individual or his probable length of life. However, an individual with a pathologically high blood-pressure is like one who is excessively overweight; such a person is functionally less capable and in greater danger than a normal one. Effective remedies against high blood-pressure have not yet been found. The best available at present is a healthy mode of life, which should begin while one is still young, and not when the blood-pressure is already pathologically high.

Hardening of the Arteries. For the most part the blood vessel (a) in Figure 129 is healthy. Its wall is smooth, round in cross-section, and it carries $3\frac{1}{2}$ ounces of blood per minute to a certain area of the body. In the course of years patches may appear on the internal surface of this blood vessel. The previously clear cells become cloudy, swell, and die, giving rise to an ulcer of the inner wall of the vessel (x). These patchy

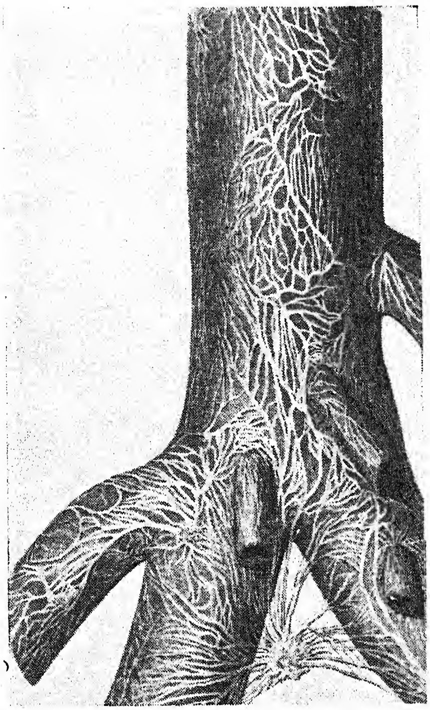


FIG. 130. *A network of vasomotor nerves surrounds the vascular wall. When stimulated, these nerves cause the blood vessels to contract, thus raising the blood-pressure.*

ulcers are the actual disease. All further phenomena are protective measures against the formation of ulcers, and processes to heal those already present. Just as cracks in a ceiling or house wall are repaired by plastering them, similarly in the body connective-tissue cells wander into all places where injuries occur

FIG. 131. *How the vasomotor mechanism regulates the distribution of the blood. During mental activity the flow of blood to the brain is increased. Eating results in a greater supply of blood to the digestive apparatus.*

in order to replace the damaged tissues. It is for this reason that areas in the body where scars occur become thickened. All scars are connective-tissue formations for the protection and repair of injured tissues. In order to protect the blood vessel against a possible rupture at the ulcerated area, connective tissue grows among the muscle fibres and thickens the vascular wall both outwardly and inwardly. The vascular tube becomes harder and narrower (b). In consequence the quantity of blood flowing through the blood vessel per minute is decreased. Instead of $3\frac{1}{2}$ ounces, only $2\frac{1}{2}$ ounces pass through in one minute. The organ concerned—for example, the kidney—is poorly supplied with blood, resulting in a contracted kidney (8). Similarly, a heart or brain

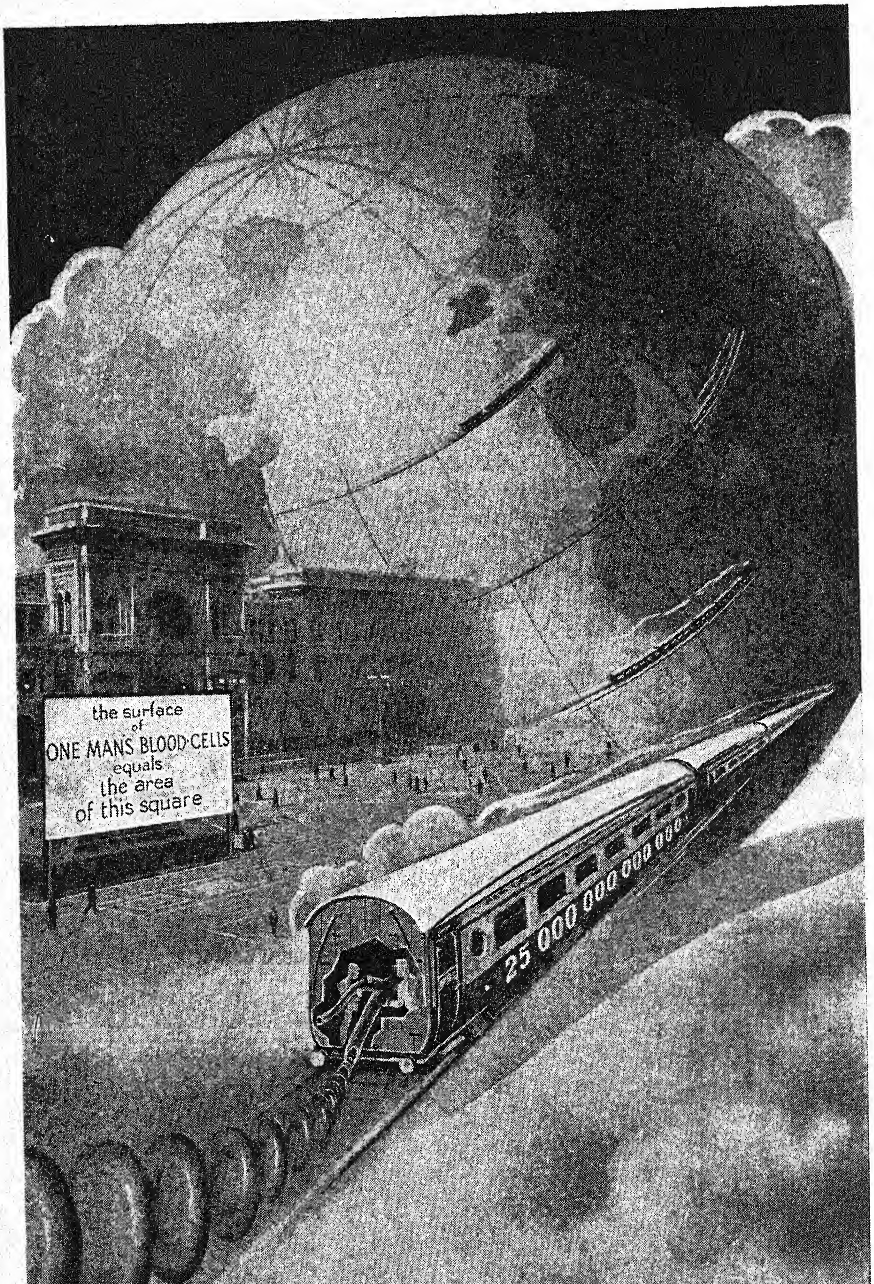
with an impaired circulation may also suffer. The brain (1-3), the heart (4-6), and the kidneys (8) are the organs where degeneration of the arterial wall makes its earliest appearance and where its effects are most marked. The narrowing of the vascular tubes creates a greater resistance for the circulation; the heart must perform more work and consequently increases in size (cardiac hypertrophy) (5). In order to force the blood through the narrowed tubes, the tension of the blood vessels is increased (high blood-pressure) (7). As a result of these various changes the arterial wall becomes hardened (sclerosed), and finally, as a result of calcium deposition, calcified. This is what is meant by hardening of the arteries, or arterio-sclerosis. It is not the beginning, but rather the end of the disease process; it is not the cause but the consequence of vascular degeneration.

Obstruction

The calcium is first deposited in the form of microscopically small granules that combine to form plaques (c), and in extreme cases the entire vascular wall may become cemented with calcium (d). These calcium deposits irritate the tissues, leading to the further growth and spread of connective tissue so that a blood vessel often becomes completely occluded. Since the channel within which it flows is no longer smooth, the blood stagnates in pockets formed by the ulcerations and calcium deposits of the vascular wall, and forms the above-described blood clots or thrombi (1), which may block the vessel. If the clots break away from the wall, they are carried off by the blood-stream and may become impacted in the vessels of the heart, lungs, or brain as emboli (3). If these emboli are large enough to cut off from their blood-supply organs essential to life, such as the heart, lungs, or brain, the patient dies at once.

Breaches of the Wall

Rupture of the vascular wall is equally frequent. Breaks in the walls of smaller vessels are of little significance. Traces of such accidents are found in the organs of every aged body. Extremely serious are ruptures of the larger arteries, either those near the heart (4), or the coronary vessels that nourish the heart (6), or the cerebral vessels (2). Rupture of the cardiac arteries results in sudden death by heart failure; rupture of the cerebral arteries produces an attack of apoplexy or, as it is more commonly known, a stroke. Since the blood vessels tend to contract spastically and to rupture when an individual is under great emotional stress and his blood-pressure is raised, people are often attacked by a stroke in the midst of exciting activities. An aged actor dies in the midst of a farewell performance; a visitor to a racecourse collapses at the finish of a close race; or a man, ripe in years, who is celebrating his jubilee, falls dead at the festive board where he has just listened to many wishes for a lengthy and untroubled existence.



MYRIADS OF BLOOD CELLS!

FIG. 132. *One person's blood cells, joined together, could encircle the globe four times!*

CHAPTER XII

The Blood

SEA WATER IN OUR BODIES. BLOOD AND LYMPH. THE BONE-MARROW. THE BLOOD CELLS. THE BLOOD PIGMENT. ANÆMIA. CHLOROSIS. RED BLOOD AND GREEN LEAVES. BLOOD PLATELETS. COAGULATION. HÆMOPHILIA. LOSS OF BLOOD. BLOOD TRANSFUSION. BLOOD GROUPS.

IF a human being were squeezed out like a lemon, no less than 11 gallons of water would be obtained. The human body contains on the average about 60 per cent water! [Fig. 133]. This is no ordinary water, but—sea water! It contains the same salts that are dissolved in the ocean, and almost in the same proportions: about 80 per cent sodium, 4 per cent calcium, and 4 per cent potassium. Blood, however, has only 2 per cent magnesium, while sea water has 10 per cent. This situation is naturally not accidental. Life originated in the sea, and by far the greatest part of the earth's early history is exclusively one of sea life.

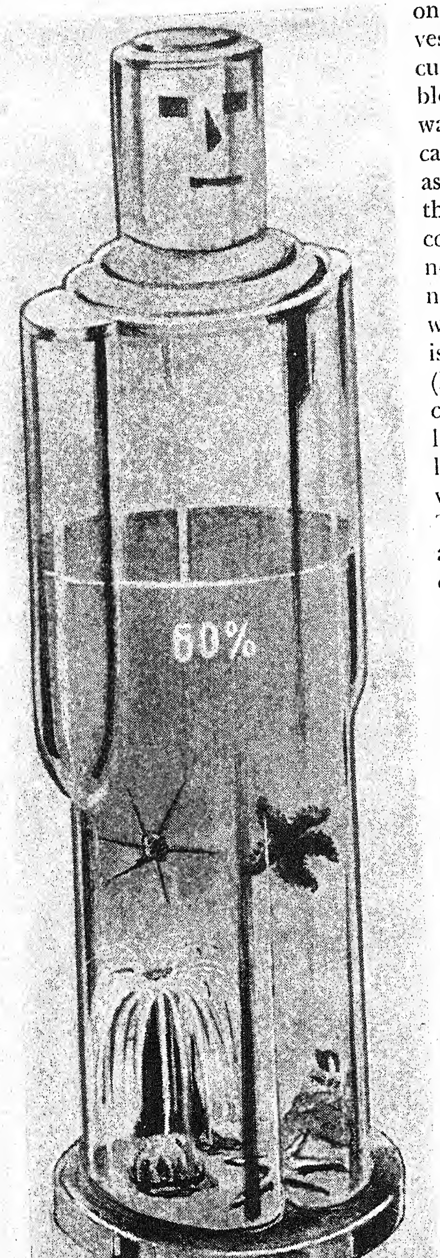
Ingenious Theory

To account for the difference between the salt concentration in the blood of vertebrates and in sea water, Macallum, who, in 1903, discussed the theory that life originated in the sea, suggested that during the early Cambrian period, when terrestrial animal life is believed to have arisen, the composition of the ocean was quite different from that found at present. According to Macallum's idea, the salt concentrations found in vertebrate blood today reflect the concentrations prevailing in the sea water during the geological era in which the ancestors of modern animal forms emerged from the sea and took to the land. Thus it has come about that while we walk on dry land a large part of our body consists of sea water. If one pricks a finger and instinctively places it in one's mouth, it is evident that the blood has a salty taste. Tears are likewise salty; the urine also has a high salt content, so that after evaporating it leaves a crusted residue of salts.

Tropical Sea Life

The body fluids are not cold, but have a temperature of 104° Fahrenheit. If they were permitted to flow out of a human body, they would fill a fairly large aquarium in which tropical sea life could exist. The cells of the human body are tropical sea animals, living in a tropical ocean with a temperature of 104° Fahrenheit and a salt content of 1 per cent. If we could descend into the interior of the human body and examine the life of the cells with a microscope, we should be looking at the depths of a tropical ocean and observing the life and activities of extremely tiny aquatic animals which in their totality make up our body.

Blood and Lymph. The human body is not an aquarium in which the sea water stands still; instead, the fluid circulates within the body. Part of the body fluid, approximately



one gallon, is contained in the blood vessels [Fig. 134 (I)] and is kept circulating by the pumping heart. The blood water oozes out through the walls of the minutest vessels, the capillaries, and flows among the cells as tissue fluid so that all the cells of the human body are bathed by a constant stream. Since it contains no red blood cells and consequently no longer has a red colour, the fluid which oozes out of the blood vessels is known as lymph or " body water " (II). After the lymph has bathed the cells, it collects in special tubes, the lymph vessels. These unite to form lymph trunks that empty into the vascular system near the heart (III). Thus the human body has not only a blood circulation but also a lymph circulation.

Part of the lymph is not derived from the blood vessels, but from the intestine. From the small intestine some of the products of digestion are absorbed into the lymphatic system by way of certain vessels known as the lacteals. Materials carried by the lacteal vessels empty into the

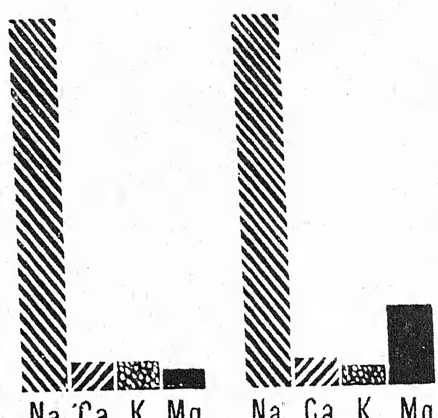


FIG. 133. *The human body consists of 60 per cent water, containing sodium (Na), calcium (Ca), potassium (K) and magnesium (Mg), in roughly similar proportions to the ocean. The diagram shows these proportions: (Left) human blood; (Right) sea water.*

main lymph trunk, the thoracic duct (III). In the course of its path through the lymph vessels, the lymph passes through the lymph glands, where the leucocytes, or white blood cells, are born. These latter, indicated as black dots in the diagram, flow into the blood with the lymph so that in addition to the red blood cells the blood also contains leucocytes of various types.

The Bone-Marrow. The birthplace of the blood cells and leucocytes is the bone-marrow. If one examines an opened bone, the reddish-grey, spongy marrow is seen in the cavity of the bone [Fig. 135]. When this tissue is examined under the microscope, it is found to consist of a network of blood vessels and connective-tissue fibres, between which lie innumerable cells (1). The marrow cell is the progenitor of the blood cells and various kinds of leucocytes.

The Blood Cells. In its youth, as long as it still lives in the bone-marrow, the blood cell is a genuine cell with a nucleus and nucleolus. Examination of a youthful blood cell reveals that it possesses a complex structure (2). However, before it leaves the bone-marrow for the blood-stream, it loses the nucleus. The ripe blood cell is no longer a complete cell. It is no longer a living structure in the ordinary sense, but simply a mechanical apparatus, a protoplasmatic balloon filled with a pigment, which has no function except to combine with oxygen in the lungs according to the physical laws governing the combination and absorption of gases under pressure, and to exchange the oxygen for carbon dioxide in the tissues. The mature blood cell as seen in the blood vessels or in a drop of blood is a circular disk, depressed in the centre and lacking a nucleus (3). If a finger is pricked and the resulting drop of blood examined with a microscope, one sees a picture which makes anyone view-

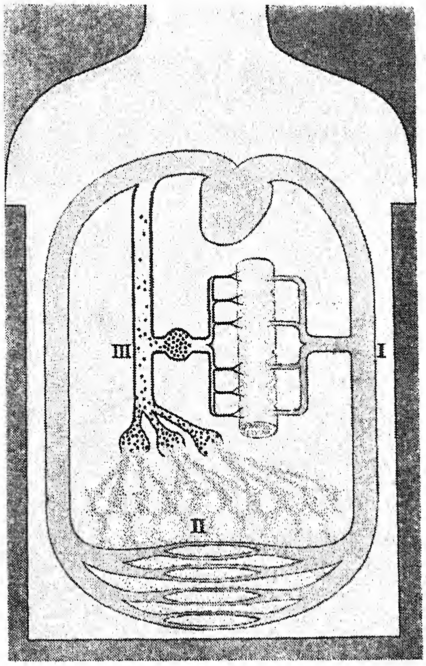


FIG. 134. *The circulation of the body fluid. A part of the fluid circulates in the vessels as blood (I). Fluid passes continually from the blood through the finest vessels (capillaries) into the tissues, and as tissue fluid fills the intercellular spaces (II). From there it returns, by way of the lymph vessels and lymph nodes (III), into the circulatory blood. Between I and III is the intestine, from which a part of the food is likewise absorbed into the lymph system during digestion.*

ing it for the first time exclaim with astonishment. Innumerable small disks float about—5,000,000 in a cubic millimetre ($\frac{1}{15000}$ cubic inch). At this point let the reader stop for a moment and glance through this volume. Try to think of how many

letters the text of this book probably contains. Now imagine this book growing smaller until it is contained within this O. This O becomes filled with water and the letters float out of the text. It is certainly an imposition on the human imagination to suggest and think of anything so fantastic. Nevertheless, we would still be far from the truth, for even then the O would contain only one quarter as many letters as it would blood cells if it were filled with blood. Naturally, it is almost impossible for the mind to grasp such magnitudes; one can only marvel.

Chains of Cells

Approximately 22 to 25 million million blood cells float about in the 9 pints of blood contained in the human body. If the blood cells of a human being were dropped one by one from a travelling train, so that they would remain lying like coins between the tracks, they would form a bead-like chain; if the cells were not enlarged as in Figure 132, but retained their natural microscopic size, the train would have to travel almost four times around the earth before the last blood cell had been added to the chain.

If the cells were not arranged like a chain, but were to be woven into a carpet, it would cover an area of about 4,900 square yards. Man has so many and such small cells in his blood in order that it may have as large a surface area as possible within the smallest possible space. The 25 million million blood cells have a total surface area of about 4,900 square yards, by means of which they come into contact with the respiratory gases of the atmosphere. At any given moment one quarter of the blood contained in the human body is to be found in the lungs, which means that about 1,200 square yards of blood-cell surface area are constantly exposed to the air. So great is the contact surface between the blood and the air in the lungs that an individual going for a walk may be regarded as actually exposing about 1,200 square yards of the living internal surface of his body to the air. This surface is not stationary, but moves past the air chambers of the lungs with the blood like a moving belt. Every second 2 million million blood cells pass by the air chambers of the lungs—that is, in every second a tissue surface of 370 square yards comes into contact with the respiratory gases of the atmosphere!

The Blood Pigment. The blood cell is filled with the blood pigment hæmoglobin, which has a strong attraction for atmospheric oxygen. The number and size of the blood cells are adapted to the oxygen need of the bearer. Worms have no blood cells, while cold-blooded amphibians have large but relatively few cells in their blood (30,000 in 1 cubic millimetre).

Why the Blood Count Varies

With the appearance of warm-bloodedness, the blood cells become smaller and correspondingly more numerous. Those animals that are (1) warm-blooded, (2) small, thus losing more body heat, and (3) inhabitants of mountain regions, have the smallest and most numerous blood cells. The llama of the Cordilleras and the musk deer of the Himalayas have the smallest and most numerous of all: 13 million in one cubic millimetre! In the matter of blood-cell production human bone-marrow adapts itself remarkably to the needs of the body. The air in the lowlands

is under greater pressure and contains more oxygen than that at high altitudes. Consequently at low altitudes an individual needs less air, and accordingly a smaller internal respiratory surface—that is, fewer blood cells. On the other hand, if he ascends to a high altitude, he enters a rarefied atmosphere containing less oxygen, where he must breathe more rapidly and deeply, so that more blood cells are required. The blood-cell count is indicative of the altitude at which an individual lives.

On the average, however, the inhabitants of London, New York, and Amsterdam have a count of 4,700,000 cells per cubic millimetre of blood. In Switzerland the count varies at different places within the country. In Basel, at an altitude of about 918 feet, the average blood count is 5 million cells per cubic millimetre; in Zürich, at about 1,345 feet, it is 5.5 million; at Davos (about 5,000 feet), 6 million; and at St. Moritz (about 6,000 feet), 7 million. Among the inhabitants of the Cordilleras who live at altitudes over 13,000 feet, the number of blood cells rises to 8 million [Fig. 136].

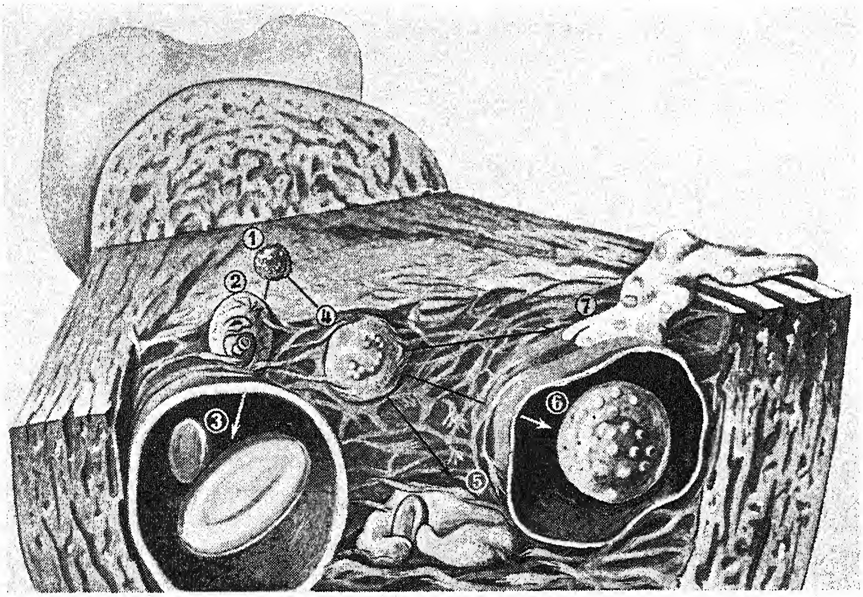


FIG. 135. *The bone-marrow—birthplace of the blood corpuscles. At (1) is a bone-marrow cell, progenitor of the red blood cells and leucocytes (white blood cells); (2) a young red blood cell with nucleus; (3) a red blood corpuscle which has lost its nucleus and become mature; (4) immature leucocytes; (5) mature leucocytes wandering through tissue; (6) a leucocyte inside a blood vessel; (7) a wandering giant leucocyte.*

Sooner or later every cell undergoes disintegration and is replaced by a new blood cell. The rate of formation of the new cells keeps pace with the destruction of the old ones. It is clear that this replacement process must be very rapid, and, indeed, the productive power of the bone-marrow is incomparably greater than that of any other organ in the body.

Anæmia. Anæmia is a broad term which designates a decrease in the number of red blood cells either as a result of a destruction or diminution of the cells themselves, or because of injury to the bone-marrow. A decrease in the number of red cells in the blood may be brought about in a large number of ways which may be classified as follows:

1. Actual loss of blood through bleeding.

2. Destruction of blood cells and injury to the bone-marrow by bacterial or other poisons. Such poisons may be chemicals taken as medicaments or absorbed by workers in certain chemical industries. Prolonged infections sometimes produce similar results.

3. The absence of a chemical factor necessary for the normal functioning of the bone-marrow and the production of red blood cells. This is the case in pernicious anæmia and sprue. The disturbance in the production of red blood cells is reflected in the condition of the blood. There is an extreme decrease in the number of red cells, yet each cell contains an abnormally large quantity of the blood pigment, hæmoglobin. The cells are very irregular in form and size, both small and giant forms being present.

4. Finally, the bone-marrow may be attacked directly by extensions of malignant tumours. In such cases the bone-marrow is replaced by abnormal tissue which interferes mechanically with the blood-building function of the marrow.

Chlorosis. An interesting form of anæmia which has now become rather rare is that found particularly among young girls and known as chlorosis. Such individuals develop a peculiar greenish pallor, with considerable weakness, loss of appetite, digestive disturbances, and constipa-

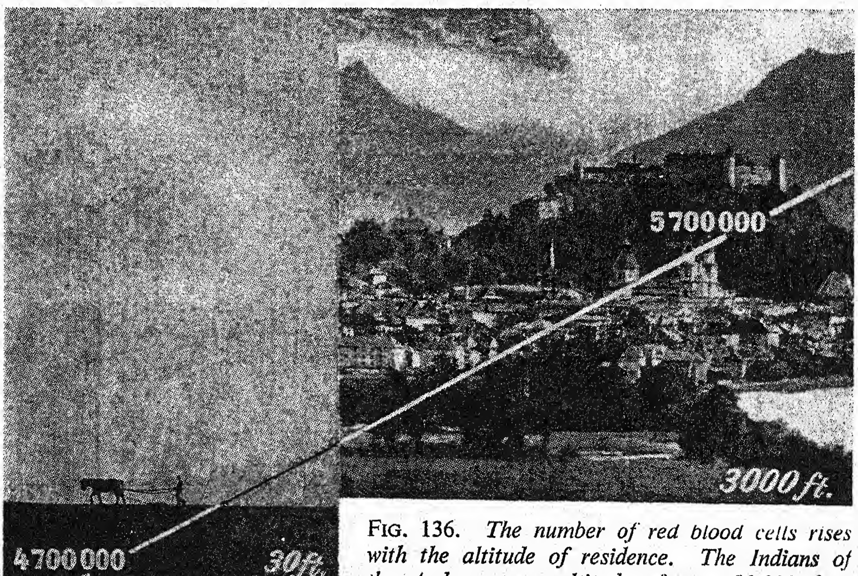
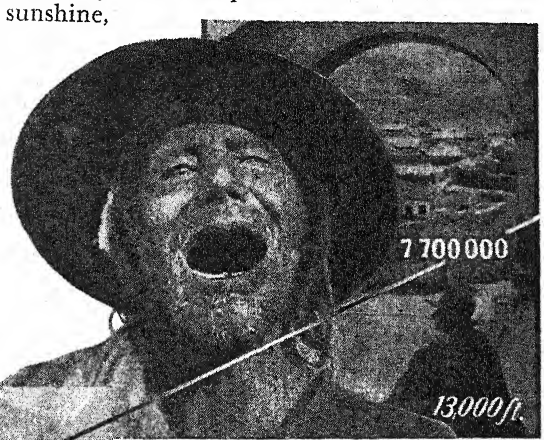
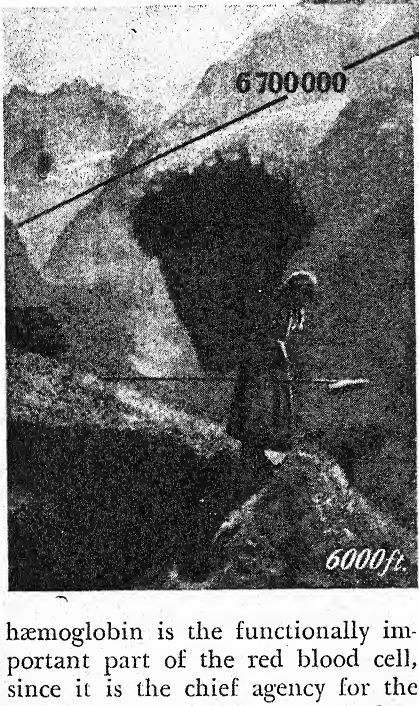


FIG. 136. *The number of red blood cells rises with the altitude of residence. The Indians of the Andes, at an altitude of over 13,000 feet, have nearly twice as many red blood cells as people living near sea-level. This increase in the number of blood cells compensates for the lower oxygen content of the air.*

tion. The number of red blood cells is almost normal, but there is a considerable diminution in the hæmoglobin content of each cell so that they appear very pale. This condition improves rapidly under the administration of iron in almost any form. Fresh air, plenty of sunshine, and adequate quantities of nourishing food, including iron-containing substances, are of great value. The iron stimulates the production of red blood cells and increases their hæmoglobin content, thus correcting the essential functional disturbance in this condition. The





hæmoglobin is the functionally important part of the red blood cell, since it is the chief agency for the transport of oxygen and carbon dioxide in the body. The ability of hæmoglobin to combine with and to transport the respiratory gases is associated with the presence of iron in its composition.

Red Blood and Green Leaves. The pigment of the blood is closely related to chlorophyll, the green pigment of plant leaves. Like the blood pigment in the animal body, chlorophyll is contained in small round granules. The chlorophyll granule and the blood cell are cousins. Chlorophyll itself contains magnesium instead of iron, but it attracts iron compounds from the soil. For this reason chlorophyll-containing green plants have a high iron content, while pale plants lacking chlorophyll are poor in iron. Both animals and plants require sunshine for the formation of their pigments.

The old, worn-out blood cells are taken out of the blood-stream by various organs, especially by the liver. Next to the lungs, the liver is the most sanguineous organ of the body; at any given moment one quarter of the blood in the body is found in the liver. Situated within the walls of the liver vessels are star-shaped cells; one might even call them "starfish" cells, for they bear an astonishing resemblance to star-

fish. These cells extend polypoid arms and remove the old worn-out cells from the blood-stream in order to destroy them [Fig. 137]. The iron-containing blood pigment is passed on to the liver cells (2), which deal with it in a twofold manner. One part is used in the formation of bile; a green bile pigment named biliverdin is made from hæmoglobin (3). Bile flows through the bile canals into the gall-bladder and then into the intestine.

Foods Rich in Iron

The body loses $\frac{1}{250}$ of its iron daily by way of the bile and the fæces. This loss must be replaced, and in consequence man needs foods containing iron. Mother's milk, as well as cow's milk, is relatively deficient in iron. During the last days before a child is born, the mother supplies the child with large quantities of iron from her own blood. The child receives a supply of iron for its journey into life. This covers the needs of the child during the nursing period. After six months this supply is used up. For this reason infants often become anæmic during the second half of the first year, especially if they are fed only on milk. At the end of the first six months at the very latest a child should receive carrots, spinach, orange juice, tomato juice—for all pigmented fruits and vegetables contain iron. Non-pigmented foods: milk, sugar, rice, fat, egg white, and fish, are lacking in iron. Among pigmented foods, spinach, lettuce, carrots, tomatoes, oranges, cherries, red meat, egg yolk, and blood contain a good deal of iron.

Blood Platelets. In addition to the red blood cells, the blood also contains two other cell types, the blood platelets and the leucocytes (or white blood cells). The blood platelets [Fig. 137 (7)] are extremely small. In diameter they are only $\frac{1}{3}$ as large as the red blood cells, and in volume only $\frac{1}{15}$. There is one platelet to every ten red cells, so that there is a total of $2\frac{1}{2}$ million million blood platelets. They are not only extremely small, but also very sensitive, and so are liable to break up under certain conditions and quickly disappear. Their significance is still somewhat obscure. The only function which can be ascribed to them is in connection with the clotting of the blood.

Blood Coagulation. The blood flowing within the circulatory system does not coagulate while it is in contact with the smooth vascular walls. Nor does it clot when it is permitted to flow carefully into a very smooth or lubricated glass vessel. A glass rod may even be dipped into the blood without causing coagulation. However, if a wooden rod is used a general clotting process sets in. Similarly, the blood coagulates when the vascular wall is injured.

Fibrin Threads

As a result of the rupture of the wall of a blood vessel, a very complex process, consisting of several phases, is initiated which ends with the clotting of the blood. As the first visible evidence of clotting one sees very fine threads of a material called fibrin running in every direction through the blood. The fibrin threads usually form about certain centres consisting of disintegrating platelets [Fig. 138 (a)]. The threads form a network entangling all the blood cells like flies in a spider's web. The moving blood-stream comes to a standstill and is transformed at

this point into a kind of cell swamp. The fibrin threads that appear in the blood are firm and highly elastic. If fresh blood is whipped with an egg-beater, the fibrin threads adhere to it as they form, and may thus be withdrawn from the blood. After being washed in water they are seen to be perfectly white and to resemble bast fibres (b). Blood-clotting protects the body against loss of blood. Clotted blood exhibits a surprising resemblance to absorbent cotton (c). Clotted blood is nature's absorbent cotton, and a blood clot is a cotton plug inserted into the blood-stream by nature. On the basis of the ability of the blood to clot it may be said that everyone carries an invisible first-aid kit in the blood.

Hæmophilia. The rapidity with which blood clots varies greatly among different individuals. Persons whose blood clots very slowly or not at all are known as bleeders, and the condition itself is called

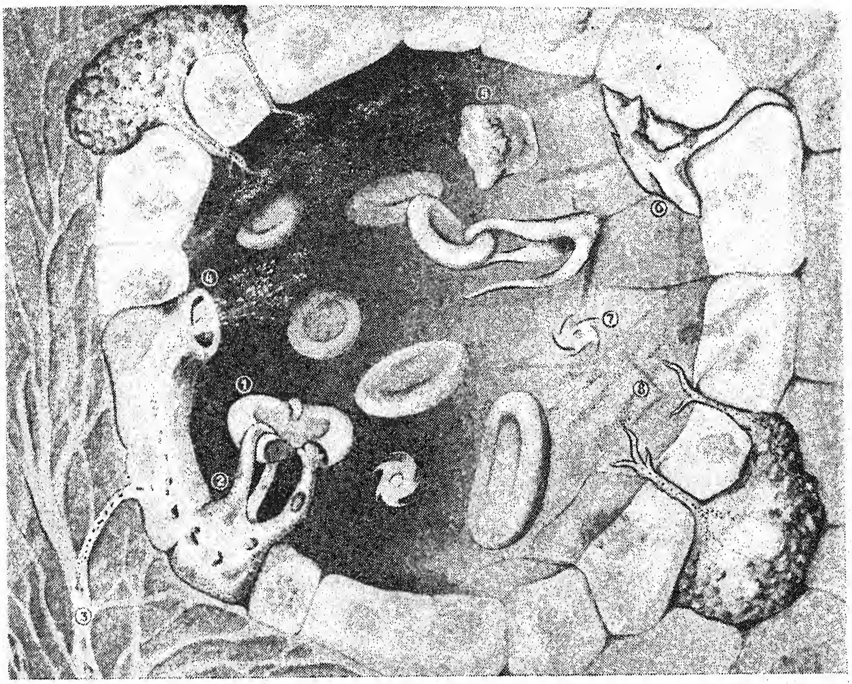


FIG. 137. *The life of the blood—a view inside a liver-vessel. The walls of the minute liver-vessels contain stellar cells which extend their polypoid arms and remove the worn-out blood corpuscles from the blood-stream (1 and 2). From the blood pigment the liver cells prepare bile pigment (3), and from other constituents of the blood cells a hormone (4), which stimulates the formation of new blood cells in the bone-marrow. The blood-stream contains floating leucocytes (5), which attach themselves to the vascular wall and creep through its interstices (6). The smallest cells of the blood are the thrombocytes, or blood platelets (7), which participate in blood coagulation. Some of the nutritive substances (8) circulating with the blood are ingested and stored by storage cells situated behind the vascular wall (Lower Right).*

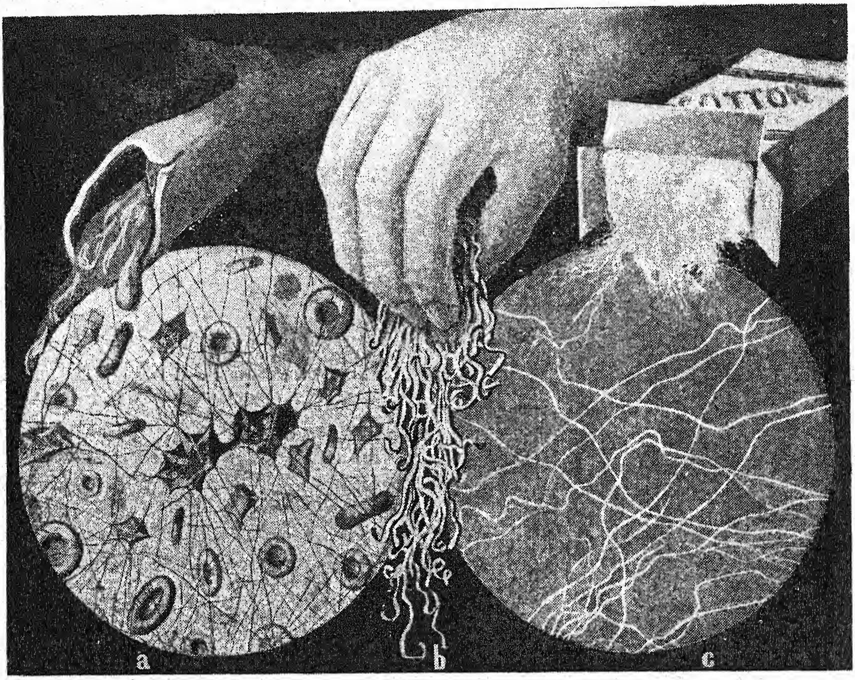


FIG. 138. *In coagulating blood (a) there are formed elastic threads of fibrin, a substance resembling bast fibres (b), which entangle and arrest the blood cells. Thus the fibrin stanches the ruptured blood vessels, acting like a plug of cotton-wool (c).*

hæmophilia, which is very rare. The condition is hereditary and sex-linked. The disease appears exclusively in men, but is never transmitted directly from father to son. It is transmitted from the father to a daughter who herself remains immune, and by her in turn to her son, the grandchild of the sick father. As a result we have the following remarkable rule: The sons of a bleeder do not suffer from and do not transmit the disease. The daughters of a bleeder are themselves immune. Among *their* sons, however, the grandfather's disease reappears, as happened with the son of the last Russian Czar, who was several times at the brink of death. Numerous outstanding European physicians were summoned to the Czar's court, but none of them could help him, so that the parents, who were greatly concerned for the life of the only successor to the throne, invoked the protection of the "miracle-working" monk, Rasputin, who played a fateful and sensational role at the court of the Czar. The same situation recurred at the Spanish court. The Spanish Crown Prince was also a bleeder. Thus two of the greatest dynasties of European history, the Spanish in the west and the Russian in the east, ended with uncrowned successors who were bleeders.

Loss of Blood. Man can sustain a loss of blood amounting to as much as one third of the total quantity of blood in the body. The bone-marrow responds to a loss with increased activity, and replaces the lost

blood with relative rapidity. The rapidity with which a healthy person recovers from a loss of blood is astonishing.

The situation is very different, however, when the body is sick or weakened. The body is much more sensitive to loss of blood during an operation, when the brain, including the vasomotor centres, is under the influence of an anæsthetic, when wounds are created or body cavities opened, as well as after the operation when the vital energies of the body are required for the healing of wounds. Similarly, repeated blood losses are poorly tolerated even when they are small. The bone-marrow becomes accustomed to this stimulus and no longer responds to it. Chronic, bleeding intestinal ulcers, for instance, from which slight quantities of blood are lost daily, eventually weaken the body like the constant blood-cell losses of malaria.

Blood Transfusion. In order to compensate for blood lost in hæmorrhage, or to restore the circulation in shock by filling the paralysed and dilated blood vessels with fluid, a salt solution, corresponding in its physical properties to those of the body fluid, has, for many years past, been introduced into the circulation, or blood has been transfused from the body of a donor into the circulation of the recipient.

Blood Donors

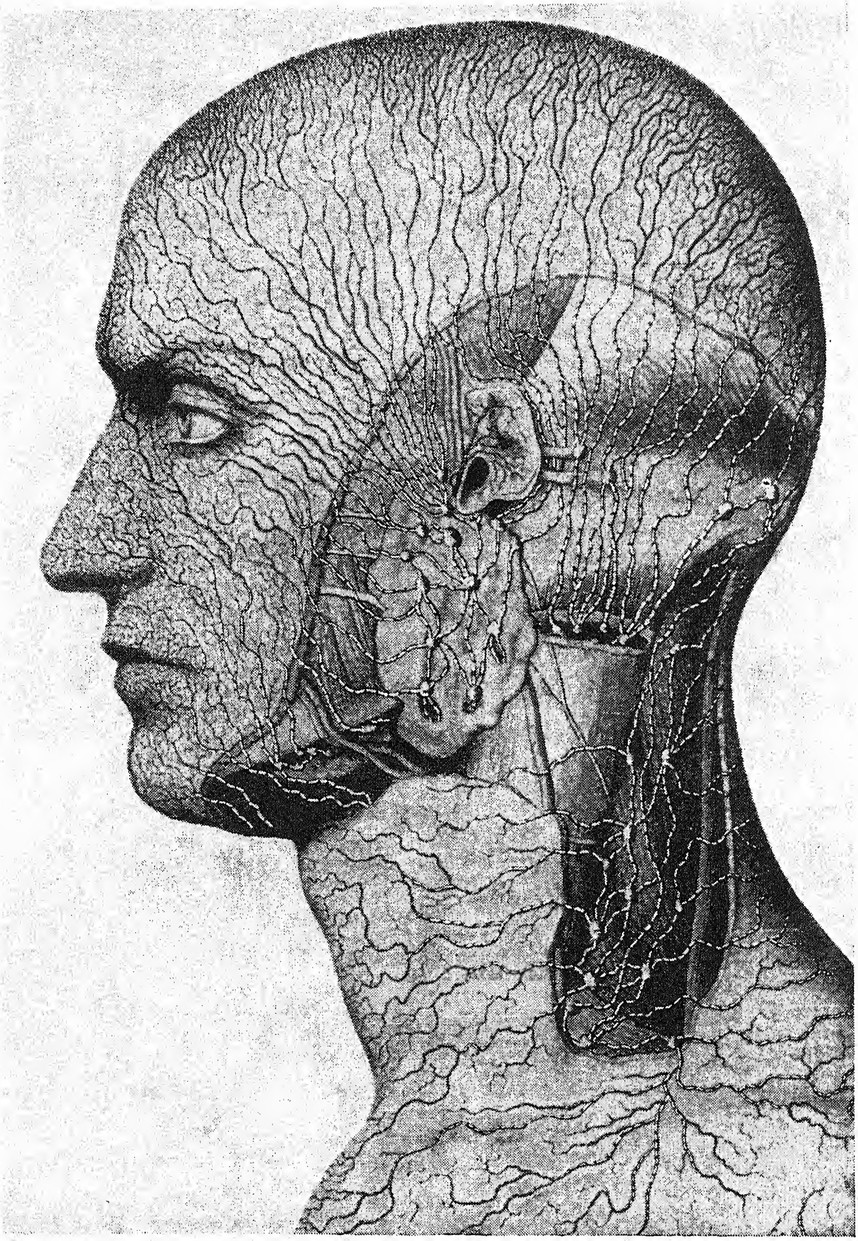
The early experimental attempts at blood transfusion were often fatal because animal blood, in particular that of sheep, was employed. The transfusion of animal blood into the human body is dangerous because of the heterogeneity of the bloods, and has now been completely abandoned. Today only the blood of healthy human beings is used for transfusion. In every city there are " donors " who give blood because of a desire to help. Many people have given blood a hundred times without injuring their health or interrupting their work even for a single day. Usually a half-pint to a pint of blood is transfused in the course of a blood transfusion.

Blood Groups. Even blood transfusion from man to man cannot be performed with impunity. At the beginning of this century, when blood transfusion, after having been discarded for decades, again became " modern," a remarkable observation was made.

Agglutination

It was discovered that approximately half the transfusions were well tolerated, while in the other half of the cases the patient's condition became worse. In some cases the patient even died soon after the transfusion. Investigation disclosed that there are different kinds of human blood—in fact, no fewer than four major types—and that the proteins of one type of blood are " foreign " to the blood of the others.

The relationship of blood types, or blood groups as they are generally known, is ascertained by means of the phenomenon of agglutination. If a drop of one blood type is added to the blood, or to the blood water (serum), of an incompatible "foreign" type, the blood cells become clumped together. This is known as agglutination. Since agglutination is the precursor of blood-cell destruction, it is a matter of great significance in performing a transfusion to make sure that the blood cells of the donor will not be agglutinated by the serum of the recipient and consequently destroyed.



THE LYMPH-VESSEL NETWORK

FIG. 139. *The entire surface of the body is pervaded with a network of lymph-vessels, whose function is to break down and absorb foreign substances penetrating the skin and filter them through the lymph nodes, so that the body's interior remains sterile and clean.*

CHAPTER XIII

Lymph

LYMPH AND CEREBROSPINAL FLUID. THE LYMPH-VESSELS. LYMPH NODES. TONSILS AND APPENDIX. LYMPH GLANDS. THE SPLEEN. THE LEUCOCYTES. WANDERING CELLS. WOUNDS AND WOUND-HEALING.

FIGURE 134 represents diagrammatically the relation of the lymphatic system to the bloodstream, and the manner in which lymph arises from the blood: blood water oozes out of the most delicate vessels, the capillaries, and occupies the intercellular spaces. Figure 140 shows how the lymph drips out of the capillaries at one of the chief points for the production of brain lymph, or cerebrospinal fluid. If a calf's brain is cut open several narrow spaces can be seen inside; a delicate, cobweb-like vascular network hangs from the walls of these spaces.

Cobweb Tissue

If a piece of this tissue is torn off and examined with a magnifying glass, one recognizes the tufts represented in the accompanying illustration. It is evident that they branch off from the vessel suspended from the roof of the cerebral cavity. If the tufts are examined with a microscope, one sees picture (b). Each tuft is a small bag, consisting of a layer of delicate cells, within which a fine branch of the blood vessel breaks up into a capillary loop. Blood water drips from the latter and forms a shallow lake on the floor of the cavity. If the tufts of an unborn child's brain secrete too much cerebrospinal fluid, the increased internal pressure pushes the soft skull bones apart so that the child is born with an immensely enlarged head, a hydrocephalus (water on the brain). Slight increases in the quantity of cerebrospinal fluid are insignificant; indeed, it often appears as if the slightly increased pressure exerts a favourable effect on the development of the brain.

On the other hand, however, considerable increases in the quantity of the cerebrospinal fluid naturally damage the child and hinder the development of the brain and its activities, causing severe cases of idiocy or even death. In many brain diseases the production of cerebrospinal fluid is stimulated by the pathological condition. As a result, symptoms of increased cerebral pressure are produced: headache, nausea, vomiting, convulsions, maniacal states, and ultimately death due to pressure on vital centres. In such cases the condition can be relieved by inserting a hollow needle into the spinal canal in the lumbar region and withdrawing some of the cerebrospinal fluid.

Pervading Network

The Lymph-Vessels. The lymph which oozes between the cells collects in microscopically small lymph spaces. These in turn unite to form lymph-vessels. Figure 139 represents the superficial lymph-vessels of the skin, and Figure 141 the internal

lymph-vessels of the body. The entire body is traversed by such lymph-vessels. Their number and total length surpass by far those of the blood vessels. No imagination can really picture the number and delicacy of the lymph-vessels contained in the tissues of the body.

Lace-like Tissue

Imagine a specimen of Venetian lace where each square centimetre contains twenty-five knotted stitches. Think of such a piece of lace as large as a tablecloth. Crumple this until it can be held in a fist like a creased paper napkin. Now make it so small that it can be put into a thimble—a Venetian lace tablecloth in a thimble. This enables one to form an approximate conception of the nature of the lymph tissue which traverses every tiny corner of the body with its networks and meshes.

The light, central portion of Figure 141 represents the geographic distribution of the lymph-vessel system in man. The lymph-vessels originate in the external surfaces of the body, the skin, the mucous membrane of the mouth, and the mucous membrane of the intestine. The last is actually a modified surface of the body and is in contact with the outside world. Here the most delicate branches take their origin; they are represented in Figure 142 (b). They unite to form larger lymph-vessels having approximately the same calibre as linen threads.

These larger, superficial vessels pass under the skin and membranes like the veins that are visible as bluish stripes. If they become inflamed they become visible as reddish slender streaks. Like the veins, the lymph-vessels pass towards the heart, uniting to form large lymph trunks on the way. The largest of these is the thoracic duct, which ascends from the intestinal region, passing through the thorax alongside the spinal column, and empties into the blood vascular system near the heart [Fig. 141 (h)].

Lymph Nodes. Since the lymph from the peripheral areas of the body absorbs all kinds of substances and fluids, including bacteria and toxins, it cannot be permitted to enter the blood-stream uncontrolled. For this reason it is filtered several times in the course of its journey through the body by special apparatuses. The smallest of these, the lymph nodes, are nothing but balls of cells in a framework of connective-tissue and muscle fibres. When the muscle fibres contract, they squeeze fluid and cells out of the balls. Millions of these lymph nodes are scattered throughout the body. The entire wall of the digestive canal is filled with them like a frontier occupied by ever-watchful guards.

Special Organs

Tonsils and Appendix. In various parts of the digestive canal these lymph nodes are grouped to form special organs. The two best-known groups of this kind are the tonsils, in the back of the mouth [Fig. 141 (in the head)] and the appendix attached to the cœcum (beginning of arrow III). The tonsils and the appendix are sister organs, of which the former are situated above at the entrance of the œsophagus, and the latter is in the intestinal canal at the entrance to the large intestine. Their structure is similar. Both consist of groups of lymph nodes surrounded by lymph-vessels, and both extend above the surface of the digestive canal. Figure 141 (III) shows the

lymph nodes and lymph-vessels of the appendix.

Lymph Glands. On their way to the heart the lymph-vessels pass several larger groups of lymph nodes called lymph glands. Figure 141 (I) is a semi-diagrammatic representation of the internal structure of such laboratory and quarantine station. The reaction of the gland depends on the character of the arriving lymph. If the lymph contains many foreign substances that irritate the gland, the lymph nodes produce many cells which enter the lymph-stream, then the blood-stream, and

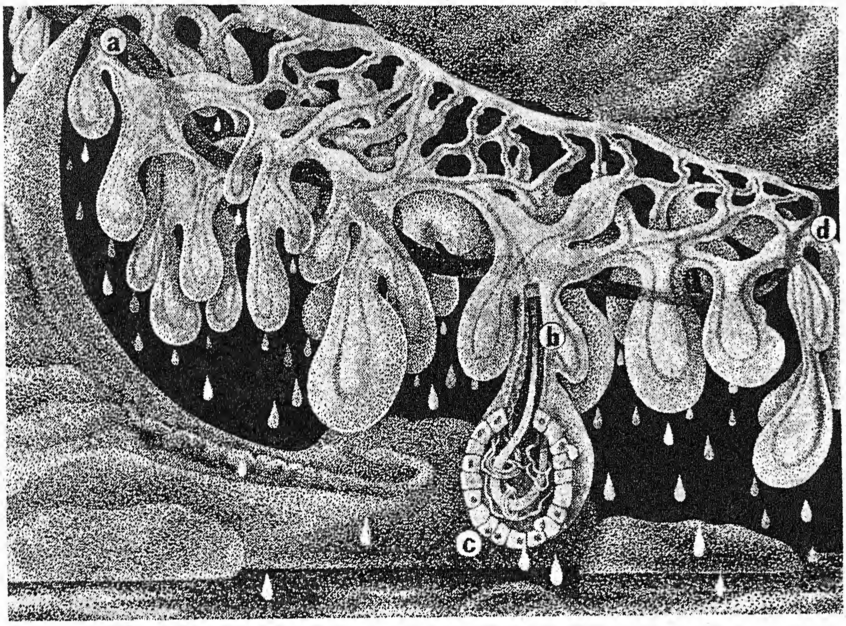


FIG. 140. *How lymph is secreted. A view inside one of the cerebral ventricles, showing how the capillary blood vessels form plexuses, or assemblages of minute loops. From the latter drips the cerebrospinal fluid, or brain lymph, which is secreted from the blood.*

a lymph gland. A lymph gland is a saccular dilatation of a lymph-vessel, in which the stream bed of the latter is widened about twenty times. Islands of lymph tissue are scattered throughout this broadened lymph-stream. The lymph is compelled to ooze slowly through this island maze as through the pores of a sponge. The lymph nodes saturate themselves with lymph, control its composition, and treat it chemically and bacteriologically. Each lymph gland is a are carried by the blood to the region of the body where the irritating foreign substance is being produced. Lymph glands are police stations that regulate the traffic in the metropolis Man; if they notice any suspicious elements in the stream of traffic, they send out their policemen, the lymph cells.

The Spleen. The spleen is a large abdominal organ which is similar in many respects to a lymph gland (II). The spleen is not a digestive

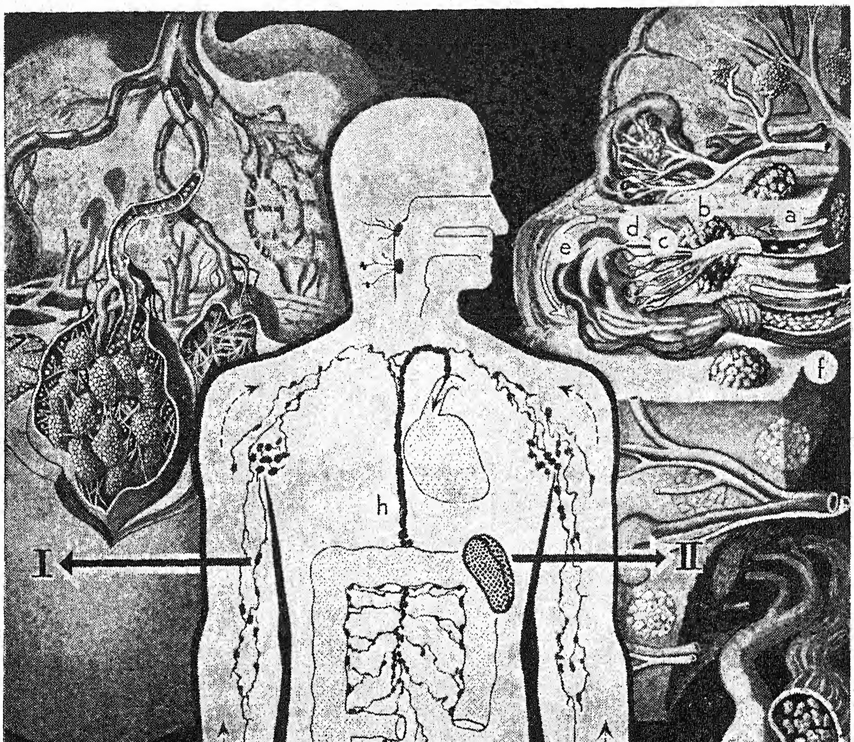


FIG. 141. *Not only the body's surface, but its entire interior as well, is traversed by lymph-vessels, as is shown above (Centre). At (I) is seen the internal structure of a lymph gland; at (II), a section of the spleen, which manufactures lymph cells. At (III) are the lymph nodes and vessels of the appendix. These sections are highly magnified.*

organ although it lies next to the stomach. It has no relation to any neighbouring organ, but is attached exclusively to the blood-stream. It could just as well be situated in some other part of the body. Figure 141 (II) illustrates the very interesting structure of this organ. The blood is carried into the splenic tissue by arteries (a). The arteries pass lymph nodes (b) on their way and receive lymph cells from them. Immediately behind the lymph nodes the arterial vessels ramify to form small tufts which because of their similarity to the hairs of a brush are known as hair-like arteries (penicilli) (c). The end of each of these branches is thickened (d). This thickening may be regarded as functioning like a brake, for immediately behind this brake mechanism the artery passes directly into a wide venous sac without any previous capillary formation (e). These venous sacs can swell up to several times their original size, and are thus able to receive immense quantities of blood. Owing to this structural arrangement the spleen is able to function as a blood reservoir. The blood flowing out of the spleen (f) contains sixty times as many lymph cells as it did when it entered the spleen (g).

Mystery of the Spleen

The functions of the spleen are not yet understood in sufficient detail. However, it does play a large rôle in blood formation during childhood, as well as in fighting blood and bone-marrow diseases, such as malaria, anæmia, syphilis, recurrent fever, etc. On the other hand, however, it can be removed without interfering with the vital processes of the body, because it can apparently be replaced by other parts of the lymphatic system. A remark made many years ago by a well-known physiologist is still true: "The spleen," he said, "is one of the most obscure and mysterious corners of the human organism."

The Leucocytes. The cells arising from the lymph organs are called lymph cells. But they also have several other names. They are called white blood cells, leucocytes, because they float in the blood as colourless bodies alongside the red blood cells.

"Scavengers"

They are also called phagocytes ("scavenger" cells) because they have the ability to ingest foreign bodies; and finally wander cells, because they are not sessile like other cells, but wander about independently. The mature cells pass out of the bone-marrow, lymph glands, or spleen, and float in the blood- and lymph-streams as colourless spheres or leucocytes [Fig. 135 (6); Fig. 137 (5); Fig. 141 (I) and (II g)]. The proportion of "white" to red cells is as 1 to 1,000.

The number of white cells present in the blood increases during digestion, after strenuous muscular exercise, during fever, and in the course of various infectious diseases. The number of white cells increases particularly when there is a purulent focus in the body. In some diseases, for example typhoid and measles, their number is decreased. After X-ray treatments there is a considerable decrease in the number of white cells. In certain skin and intestinal diseases, asthma, trichinosis, tapeworm infestation, etc., special types make their appearance. Numerous conclusions can be drawn from the number and kind of leucocytes found in the blood, and for this reason a leucocyte or white-blood-cell count

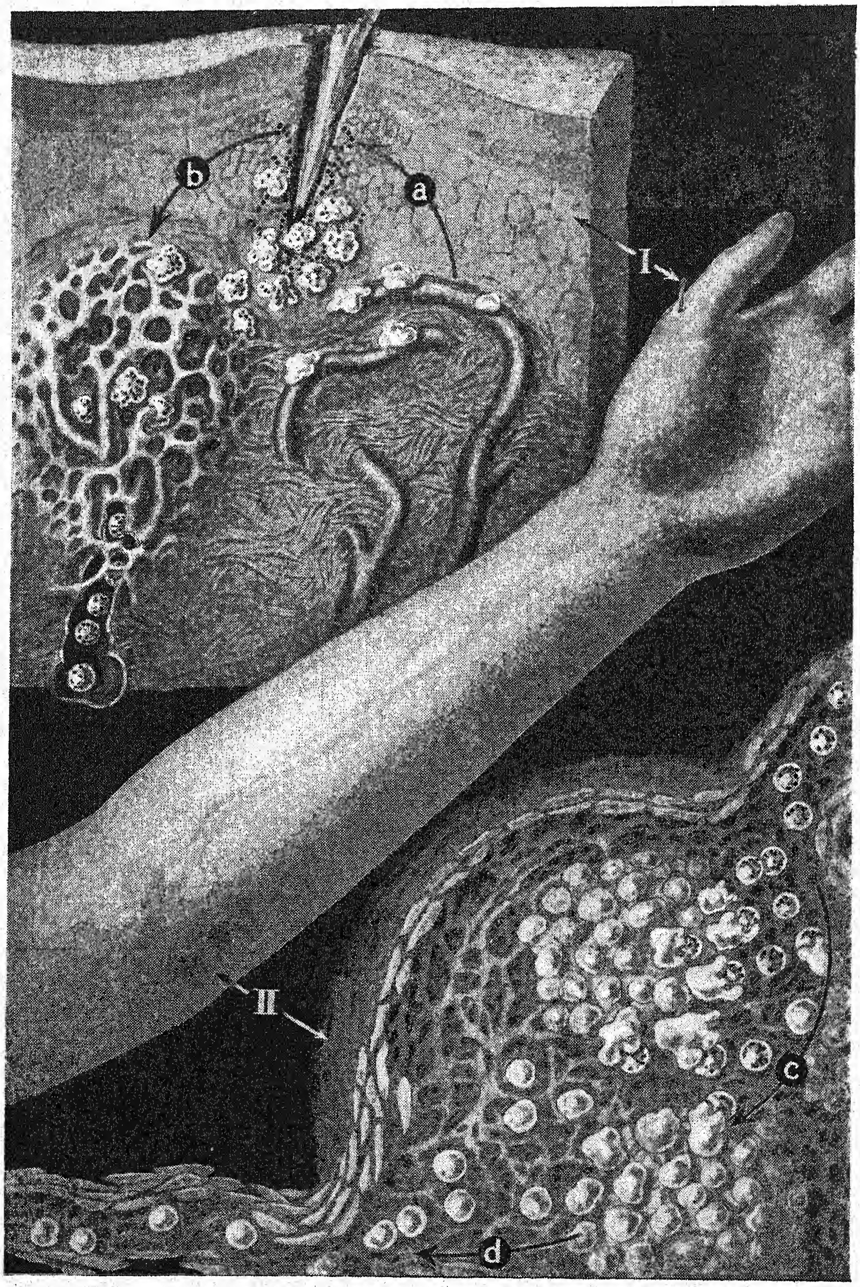


FIG. 142. *How wandering lymph cells protect us. A splinter (I) introduces bacilli into the hand. They are conveyed by wandering lymph cells (b) to the lymph glands of the elbow (II), and destroyed (c). Meanwhile, fresh lymph cells hasten to the "battle" (d).*

ought to be part of every complete medical examination.

Wandering Cells. After a lymph cell has floated about in the blood for some time, it reveals its true nature; it begins to wander and to act as a scavenger. It extends several processes, attaches itself to the vascular wall and assumes the appearances of a starfish on the wall of an aquarium [Fig. 137 (6)]. It feels its way along the wall, creeps out of the blood vessel through a narrow gap in its wall at some point, and wanders through the tissue. Where does it go? There is no spot in the body where wandering cells cannot be found. There are always several hundred billion wandering cells travelling around—in our body there are a hundred times more little individuals constantly wandering about than there are human beings on our planet. If no human being had died since the Glacial period, if every human being that had been born since then were still alive—there would not be as many people as there are wandering cells creeping about in our body.

Watchful Armies

The wandering cells are the police, soldiers, street-cleaners, firemen, and first-aid men of the cell state. They intervene wherever they find a foreign body, a dying cell, or a disturbance of any vital activity. They are led by a kind of olfactory sense. As soon as any disturbance in the activities of the body becomes noticeable, wandering cells appear from all sides. They creep out of the blood vessels, from the neighbouring lymph glands, and from the farthermost regions of the body. If a fine, open tube filled with bacteria is placed in the abdominal cavity of a frog and then removed after eight hours, it is covered with wandering cells. Owing in part to the gathering of wandering cells, the tissues swell wherever there is an acute pathological process. If a splinter penetrates the skin, it is practically besieged by an entire army of wandering cells [Fig. 142 (a), (b)]. The cells gnaw it like mice; they secrete digestive substances around it and try to dissolve it. If this does not succeed, they attempt to remove it.

Suppuration

They eat into the tissue around the foreign body so that it will become liquefied. Tissue liquefied by wandering cells is called pus. Pus is not a disease, but the result of remedial action taken by the body against some pathological disturbance. If a wound discharges pus, it indicates that there are substances in the tissues which the body wants to remove. A " clean " wound does not suppurate. A large collection of pus at any point in the body is called an abscess.

Wounds and Wound - Healing. Figure 142 depicts the processes that occur when we have hurt ourselves, and a dirty foreign body—for example, a splinter—has entered the skin, causing suppuration. The splinter (I) penetrates the skin surface, whereupon wandering cells, attracted by the substances in the wound, creep out of the nearest blood vessel and rush to the " battlefield." They gnaw at the splinter in order to digest it, or form pus by digesting the surrounding tissue.

Other foreign bodies, among them bacilli, have entered the body together with the splinter. They are attacked and ingested by the wandering cells (b). These cells, filled with

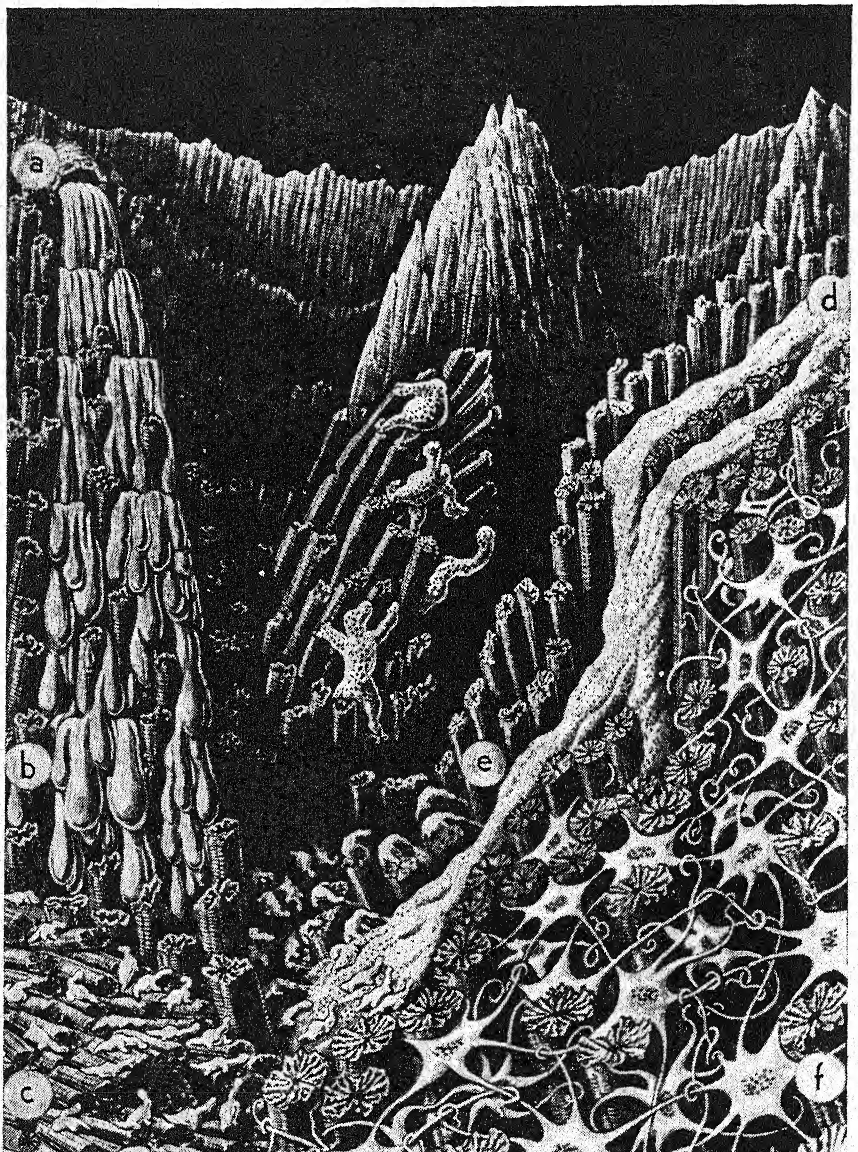


FIG. 143. *A view into the depths of a wound. From a ruptured blood vessel (a) blood flows over the torn muscle fibres (b). Wander cells (c) emerge from neighbouring tissues, attack the invading bacteria (d), and pour digestive secretions over them (e). Then young connective-tissue cells, resembling starfish with interlaced, thread-like arms, arrive and build fresh tissue over the cleansed area (f).*

bacilli, wander into the lymph-vessels and swim in them to the nearest lymph gland. If a finger has been injured, the nearest lymph glands reached by the wandering cells are those of the elbow. The cells reach this point without hindrance, but here they are intercepted by the gland. Not only does the lymph-stream carry the cells, but also toxins, dust particles, and small coal granules. All these substances are caught in the net of the lymph gland.

The lymph cells' arm-like processes catch and ingest the foreign substances as they pass by, just as polyps catch and devour small fishes and crabs. The wandering cells laden with bacilli are also devoured (c). Among the ordinary lymph cells occasionally very large cells may be found. These "giant cells," as they are called, are phagocytes that feed on phagocytes [Fig. 135 (7)].

Reinforcements

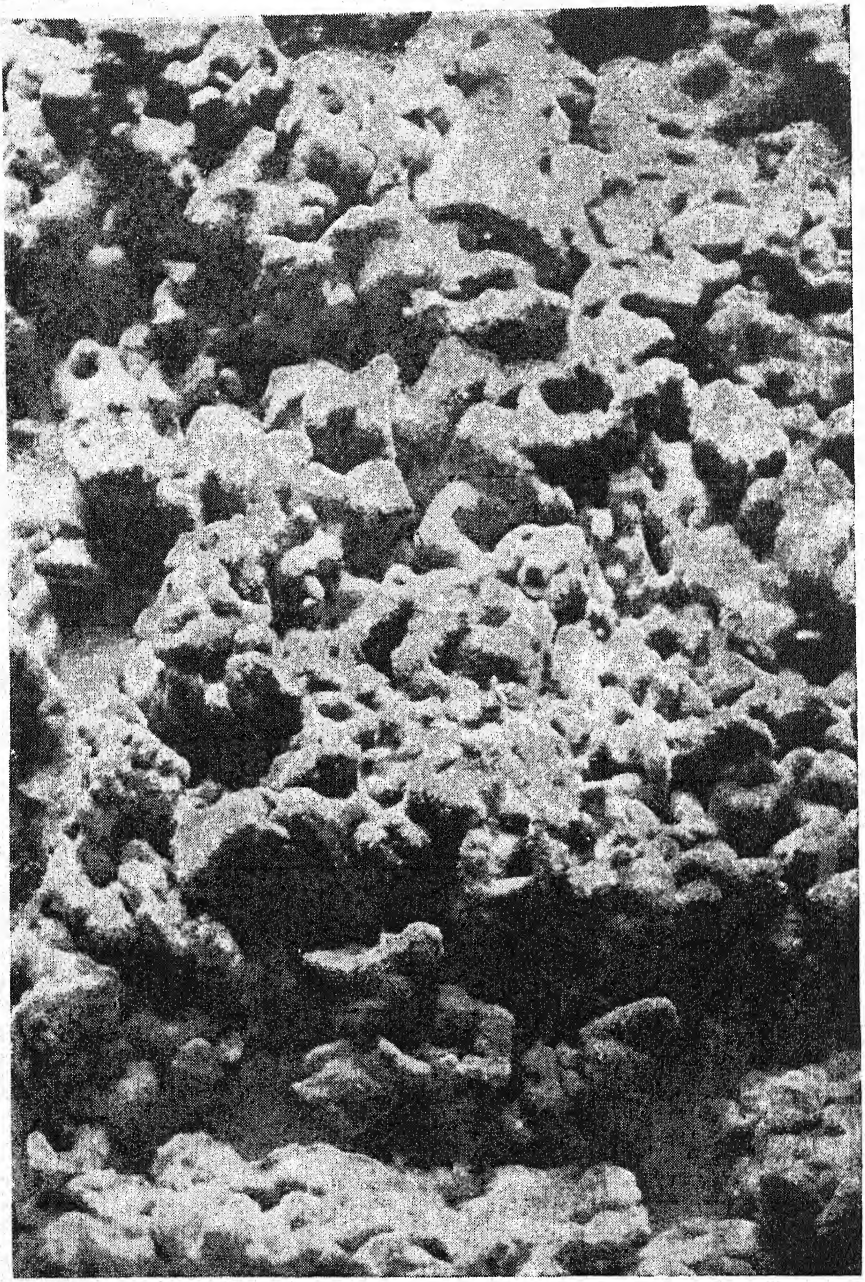
As a result of the introduction of wandering cells and foreign substances the lymph gland becomes larger, its cells multiply and grow more numerous. While wandering cells keep coming in from the "battlefield" in the finger (c), the lymph gland sends new young fighting cells into the lymph-stream in the direction of the front (d). These cells also enter the blood-stream, so that the number of white blood cells is increased. The increased number of lymph cells in the blood-stream indicates to a physician that a focus of infection must be present in the body. The swollen lymph gland is painful. When a finger wound suppurates, the lymph glands of the elbow and armpit swell (II). When someone comes to a physician with a complaint that the glands in the armpit hurt, the doctor not only examines the armpit but also looks at the hand to see whether the source of the trouble is located there.

Figure 143 depicts another aspect of the life of wandering cells: namely, in the interior of a wound. At the upper left is a torn blood vessel which has bled (a). The blood has clotted and has formed something like a frozen waterfall (b) over the stumps of the torn muscle cells that are exposed in the wound.

Barrier to Bacteria

Wandering cells creep from the depths of the tissue (c). The wound is contaminated; bacteria have entered it and multiplied (d). The wandering cells advance against the bacteria and oppose them. They want to ingest the bacteria, but before they can do this the latter must be rendered harmless and tasty by means of certain substances known as opsonins, from the Greek word meaning "to buy food." At (e) we see how they squirt these opsonins on the bacteria.

While this relentless struggle between the bacteria and the wandering cells is still raging, new groups of special wandering cells come to fill up the wound cavity with new cell tissue. They look like polyps with interlaced thread-shaped arms (f). They cover the torn muscle columns and grow together with them, thus forming granulations that are later transformed into scar tissue. The vast host of wandering cells in the army of the cell state is the best conceivable militia that any state could ever desire for its protection.



FUNGUS THAT HAS REVOLUTIONIZED HEALING

FIG. 144. *The mould* penicillium notatum, *from which penicillin is extracted, growing upon sliced potatoes. This was an early method of producing the drug commercially.*

CHAPTER XIV

Man and Bacillus

BACILLI. THE BACILLUS AS A DOMESTIC ANIMAL. THE VIRUS. THE BACTERIOPHAGE. TOXIN. ANTITOXIN. SERUM. THE SULPHA DRUGS. M. AND B. 693. PENICILLIN—THE WONDER DRUG. STREPTOMYCIN.

MOST people have a wrong conception of bacilli. At the mention of the word "bacilli" they immediately think of "enemies of mankind." To think of a bacillus as something evil is just like thinking of a murderer at the mention of the word "man." Bacilli are the most widespread creatures in the world. If it were simply a matter of numbers, one would have to say that the earth is populated by bacilli, for the total number of all other living creatures is insignificant when compared with the number of bacilli. There is no piece of soil, no dust particle in the air, no drop of water, no fly's foot, nor a single human hair which is not populated by thousands of bacilli. If a human being kisses a sterile glass plate, a dozen colonies of bacilli will develop on it—every kiss carries bacilli from one human being to another [Fig. 145]. If a fly walks on a tablecloth, it leaves tracks behind it at every step like someone walking on snow—bacterial tracks!

We Eat Bacteria!

Moreover, at any given moment when milk flows into the milker's pail, each teaspoonful of milk contains 10,000-20,000 bacteria. When the milk arrives at the railway station an hour later, the bacterial content is ten times greater. Eight hours later, when a housewife buys the milk and takes it home, each teaspoonful contains 500,000 bacteria; several hours thereafter the number has risen to 10,000,000 germs. In butter the number of bacteria is ten times greater. Half of the dry substance of cheese consists of living bacilli, cocci, spirilli, and vibrios. Bacilli are rod-shaped micro-organisms, cocci are spherical in shape, spirilli have the form of corkscrews, and vibrios are snake-like in their movements.

Germs Everywhere

Whenever human beings or animals live close together, the number of bacteria increases extraordinarily. Only a million germs live in each teaspoonful of virgin earth; a teaspoonful from a manure-heap contains thousands of millions. A spoonful of water from a river above a city contains 30,000 bacteria; the same quantity from the river below the city contains a thousand million organisms. Morning air contains little dust and therefore few bacilli, for bacilli do not live freely suspended in the air, but exclusively as passengers on dust particles. Each dust particle is a balloon with which several hundred bacilli sail through the air. In the course of a day the number of bacilli increases, and attains a maximum in the air of railway stations, cafés, and dance halls.

Man and Bacilli. Creatures that are so widespread that we inhale thousands of them with each breath cannot be exclusively harmful. Bacilli are living creatures. They have no desire to be harmful or to be useful, they simply want to live—just as we do. We call bacteria harmless if they do not disturb us: those that help us we designate as useful: the third group, which injures us, is described as harmful. This is a very arbitrary and human classification. The relations of bacilli to man are exactly like those of visible creatures.

Useful Germs

There are more than 10,000 species of bacilli. Of these 80 per cent are of no concern to us; a small percentage are useful to us and we exploit them. They make cheese, vinegar, yeast, dough, beer, and wine for us, and we use them to ferment tea and tobacco. We live together with a large number of bacilli in a sort of community of interests, just as we do with bees and the domestic animals, the dog, the horse, the cow, and the sheep.

The Bacillus as a Domestic Animal. All organs that come into contact with the outer world are colonized by bacteria; this is true of the skin, mouth, nose, air passages, stomach, and intestinal canal. This colonization is by no means accidental or anarchic in character. Here just as everywhere else in nature the bacilli also form communities. Since bacilli belong to the plant kingdom, these groups are described as the " flora " of the region where they are found. Plants do not grow at random, but form definite groupings: the flora of the tropical forest, of the desert, swamp, or mountain. One plant thrives in the sun's rays, another requires shade; one plant withdraws calcium from the soil, another aluminium compounds; a third lives on rotting leaves that have fallen from tree branches, while in the tiniest cracks of the bark live hardy mosses that find enough nourishment there to survive. No creature can exploit all the possibilities present in its habitat for the support of life. Various interstitial aspects of nature remain unused, and in these gaps other creatures are able to establish themselves. Similarly, human beings living in a city may also be regarded as a type of " flora." For example, a mine is opened and a shelter erected. Around the plant houses are erected for the workers. Once the workers have moved in, various shops are opened, and a restaurant and a cinema appear. Bacilli live in analogous communities. They are by no means lower and "simple" creatures. There are more " occupations " and " specialists " among bacilli than there are among men. In every " milieu," in water, forest humus, arable soil, in a cow's stomach, a dog's intestine, or a human abdomen, we find bacterial flora that are adapted almost exclusively to their particular habitat.

Our Bacterial Allies

In the mouth, for example, which is moistened by alkaline saliva, kept rather cool by the external atmosphere and periodically " flooded " with food, lives the " flora of the mouth " consisting of about fifty kinds of bacilli. A very different flora is found in the large intestine, where no fewer than seventy-five kinds of bacilli live in community of interests with each other and with man. Man gives them food, and they help to decompose food remnants

that are difficult to digest. Billions of living creatures leave the human body with every stool!

These bacterial colonies in various parts of the human body are not dangerous or harmful; on the contrary, they represent a community of interests which has existed for millions of years. Man and bacillus live in a symbiotic relationship; the bacillus is the oldest and most intimate "domestic animal" of man.

We ingest all kinds of bacilli almost without interruption. Not infrequently 3,000 tubercle bacilli may be found in a teaspoonful of milk. Only a few decades ago there was hardly an adult individual in whose body traces of an old tuberculous infection could not be demonstrated after death. Other pathogenic germs are similarly widespread. Diphtheria and meningitis organisms may be found in the nasal and oral cavities of individuals who are otherwise in good health. Bacilli that cause furuncles may be found on any skin, as well as streptococci that produce sepsis. Nevertheless, the importation of bacilli of the worst kind does not harm us, for reasons that are the very opposite of those generally assumed by most people. In the first place, we are not harmed because of the great number and variety of bacilli. Secondly, the ingestion of bacteria does not harm us because it takes place continually—that is, there is constant reinforcement of immunity by reinfection. A young child is endangered by unboiled cow's milk, and a newborn infant should not be given it. A three-year-old is easily attacked by infectious diseases, but an individual who has swallowed the most "dangerous" bacilli for twenty years is so used to them and has produced so many protective substances that he is immune to them, just as a habitual smoker can stand five strong cigars daily, whereas a non-smoker or a child attempting to imitate this feat would surely become sick.

The Virus. If a bacterial culture is passed through an asbestos or clay filter, the bacteria are kept back by

FIG. 145. *A kiss as transmitter of bacteria. This gelatine plate was touched by human lips. The white patches are not individual bacilli, but colonies of several million bacilli. Every kiss carries bacilli to and from the persons indulging in it.*

the fine pores of the filter; the filtrate is free of bacteria. Tuberculosis, diphtheria, or cholera cannot be transmitted by means of such a filtrate for it contains none of the bacilli producing these diseases.

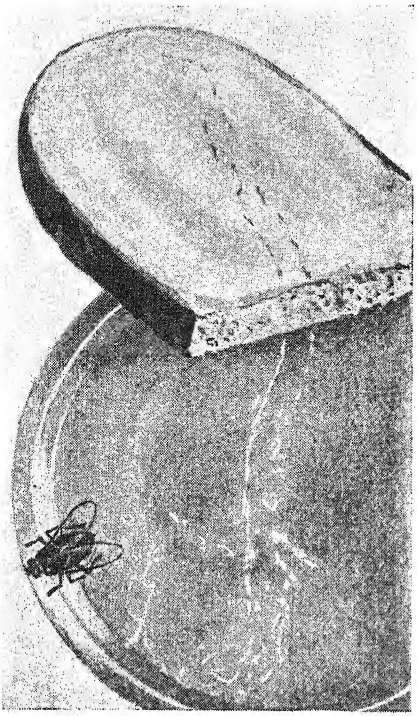


FIG. 146. *The feet of the common fly, and those of other insects, are laden with bacilli, which are deposited upon everything that they touch. The bacterial colonies on the plate above were cultured from fly tracks.*

However, the filtrate of a case of yellow fever will transmit the disease even though it contains no bacilli. Colds, influenza, and a number of other diseases are not caused by bacilli, or at least not by bacilli alone. Infection with one of these diseases requires the presence of a much smaller filterable pathogenic entity, which is called a virus. The size of the virus may be calculated from the size of the pores in the filter. It may be 20,000 times smaller than a bacillus [Fig. 147].

This illustration shows 2 cubic millimetres of blood (a), containing ten million blood corpuscles. If one of the latter is magnified five thousand times, it appears as large as the disk (b). A typhoid bacillus can swim about in such a disk, while the smaller tubercle bacillus could swim about within the typhoid bacillus. If the tubercle bacillus were magnified so that it was as large as the rod (c), a magnification of about 40,000 times, then a virus would be as large as the dot indicated by the arrow. Within the two cubic millimetres (a) there is room for ten million blood cells, four hundred million typhoid bacilli, two thousand million tubercle bacilli and two thousand million viruses.

It has not been determined whether the virus is a living creature like the bacillus, yet it may be cultured and transmitted. Until now approximately 300 species of virus have been recognized. Diseases that are caused by viruses and not by bacilli are measles, smallpox, colds, influenza, poliomyelitis, rabies, psittacosis, foot and mouth disease, swine fever, and the mosaic disease of tobacco. The virus of smallpox, which had been sought in vain for a century, has now been discovered and cultured. The first important result of such cultures has been to make it very much easier and simpler to procure the prophylactic vaccine lymph. The virus is no longer cultured in calves, but on the living membranes of hens' eggs. The second great success which has been achieved is the production of a therapeutic serum for foot and

mouth disease, which at one time caused loss to the value of millions of pounds annually. A virus is more sensitive and fastidious than a bacillus. It needs definite living conditions in order to flourish. As yet no culture medium lacking living tissue has been invented upon which a virus could be grown. It requires living tissue as a culture medium.

Living Crystals

Assuming a virus is a living creature, it is apparently on the lowest rung of the ladder of life, or at least very close to it. It has long been conjectured that the lowest types of life must be closely related to crystalline structures, and probably have the character of fluid crystals, regarding which we know that they are able to move about, adapt themselves, divide and multiply. Recently it has been discovered that the viruses of certain diseases such as the mosaic disease of tobacco can be obtained in the form of crystals! These crystals can be kept in a solid state for months, then dissolved and recrystallized, yet the virus will nevertheless retain its living and infectious character. The virus is a crystal consisting of protein compounds. In its vital organization it is probably as far beneath a paramecium as the latter is below a human being.

The Swedish scientist Svante Arrhenius proposed the hypothesis that minute forms of living matter are propelled through universal space by the radiation pressure of the stars and wander from one solar system to another. Consequently, Arrhenius reasoned, it is very probable that life is not a terrestrial privilege, but a universal phenomenon in the cosmos. The discovery of viruses may be used to support this hypothesis, for it may be that viruses not only transmit disease from one living creature to another, but life itself from planet to planet.

The Bacteriophage. When a culture of the stools obtained from a convalescent case of bacillary dysentery is filtered through a clay filter, and the filtrate is then added to a cloudy culture of dysentery bacilli, the culture assumes a clear, transparent appearance within a few hours. On examination one finds that the bacilli have been dissolved and the culture is now sterile. The addition of an extremely minute quantity of this sterile culture to a second bacterial culture produces the same result. This process can be continued almost *ad infinitum.* The active principle or substance which destroys the bacteria has been named the bacteriophage, or eater of bacteria. It is always associated with living, actively multiplying organisms, and has no action on dead bacteria whatever.

Virus or Enzyme?

There are two theories concerning the nature of the bacteriophage. Some scientists regard it as a living organism or perhaps a virus, while others believe it to be an enzyme. It was first believed that the bacteriophage would prove to be a powerful weapon in combating infectious diseases, but in practice it has so far been a disappointment.

Toxin. Bacteria damage the body in a variety of ways. The diphtheria bacillus is not active, and lies like a white sward on the tonsils; but at the same time it produces a powerful poison, diphtheria toxin, which diffuses into the blood and lymph. This toxin damages the heart, the nervous system, and the kidneys.

Having once entered a skin wound, the tetanus bacillus remains there and produces a soluble toxin, which is so powerful that one gramme is sufficient to kill 20,000,000 mice or 4,000 human beings. If the patient is left untreated, this toxin reaches the spinal cord and the brain, where it becomes so firmly anchored to the motor nerve cells that it cannot be dislodged.

Toxins and Fatigue

The action of the tetanus toxin on the motor nerve cells results in an extreme hypersensitiveness of the motor nervous system, in consequence of which trivial sensory stimuli produce terrible muscular spasms. Finally the patient dies exhausted by his convulsions or asphyxiated by spasms of the respiratory muscles. The feeling of fatigue which is present in persons suffering from various infectious diseases is generally the result of toxins circulating in the body.

Anti-toxin. When any foreign protein is introduced into the blood vessels and tissue spaces of the body, substances known as anti-bodies are produced. Certain specific anti-bodies produced in response to bacterial toxins are known as anti-toxins. These have power to nullify any effect produced by the foreign substance by combining with it. Each anti-body is specific for the foreign substance which stimulates its production. The body may be compared with a city where a policeman is sent to meet every stranger as soon as he enters the city gate and to accompany him wherever he goes so as to render him harmless. However, the body produces not only a single policeman, but always more policemen than there are foreigners to be arrested, so that after the entry of foreign elements into the blood there are always free policemen present to arrest any subsequent intruders. The body produces an excess of anti-toxin. If a person has scarlet fever, enough anti-toxin remains after the disease has run its course to ensure that every new scarlet fever organism is immediately bound and neutralized. Owing to the excess of scarlet fever anti-toxin the individual has become immune to this disease. The anti-toxins for scarlet fever, measles, and smallpox remain in the blood throughout life. Anti-toxins produced in response to other diseases, such as colds and influenza, are gradually eliminated by the body.

Serum. The therapeutic serum which is injected in cases of diphtheria consists of anti-toxin, obtained from the blood of horses that have been inoculated with diphtheria toxin, causing them to produce anti-toxin. For some diseases, such as measles, there is as yet no better remedy than to inject the sick person with the blood of people who have recently had the same disease, so-called convalescent serum.

Immunization

This blood contains the anti-toxin (passive immunization). In the case of other protective inoculations—for example, against plague, typhoid, and cholera—the individual is not injected with a serum containing anti-toxins, but with dead organisms causing the body to produce sufficient anti-bodies by means of this mild infection (active immunization) for it to resist serious infection.

The Sulpha Drugs. Modern discoveries have revolutionized the medical treatment of infectious and other germ-caused diseases of the human

body. First of all, those engaged in what is called medico-chemical research succeeded in creating a substance which they called sulphanilamide which, administered in addition to modes of treatment which had previously proved helpful, in most cases checked the activities, and ultimately destroyed the life, of the classes of germs known as hæmolytic streptococci, gonococci, meningococci and bacillus coli. These germs, if they "successfully" invade the human body, manifest themselves as puerperal fever, scarlet fever, gonorrhœa, and a few other common disorders. On pneumonia, however, this substance had no effect.

M. and B. 693. But continued research soon produced another synthetic combination which was found to be lethal to the pneumococcus, the bacterium responsible for the fatal disease, lobar pneumonia. To this substance, the name sulphapyridine was given, and it is this drug which is popularly known as M. and B. 693 (so-called because it happened to be the six hundred and ninety-third product of the chemical research and manufacturing firm of Messrs. May and Baker). Other drugs in this series have followed, some of which, including sulphathiazole and sulphadiazine, have been found effective against diseases not hitherto countered.

Penicillin — The Wonder Drug. The word "penicillin," now famous throughout the entire civilized world, was, as recently as 1929, unknown except to the small class of students of the minute vegetables called moulds —which supply the active ferments of some well-known cheeses. Many moulds of the penicillin family are among these cheese-making agents, and they are present, among others, in Stilton, Roquefort and Camembert cheeses. Camembert contains *penicillium album,* Roquefort and Stilton *penicillium glaucum;* the latter being responsible for the veins of blue which run through a mature cheese. These members of the penicillin family, however, are not those from which penicillin is made. The only species which seems to have active anti-bacterial qualities is that

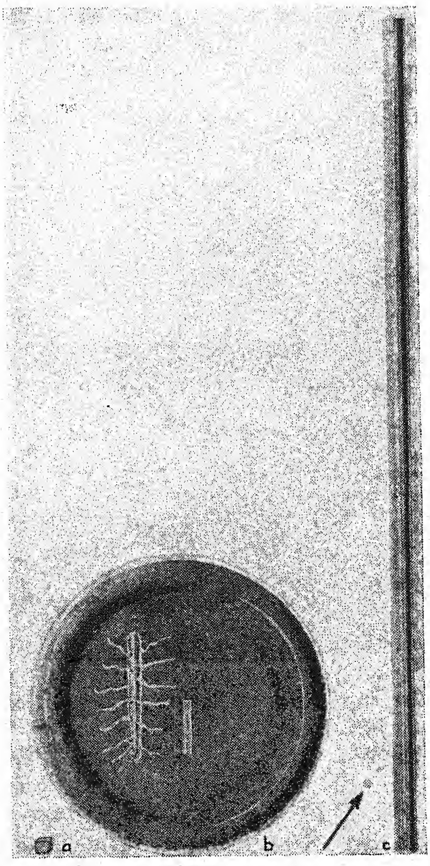


FIG. 147. *Cell—Bacillus—Virus. At (b) is a blood cell (magnified) containing typhoid and tubercle bacilli. The dot represents a virus magnified 40,000 times. In the cube (a) over four thousand million organisms could find room (Page 194).*

known as *penicillium notatum*.

Most people have heard the story of the accidental discovery of the germ-destroying qualities of penicillin moulds: how the spores of one of the groups entered the laboratory window of Professor (later Sir) Alexander Fleming and "contaminated" some plates on which various bacteria were being developed ex-

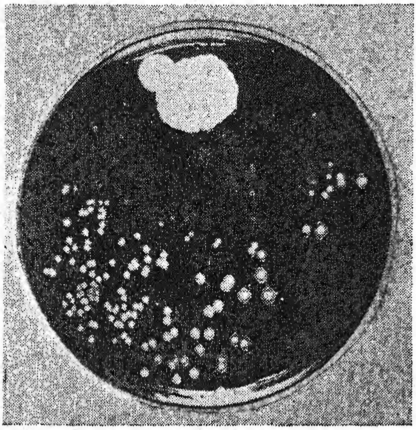


FIG. 148. *A milestone in the history of healing. The original culture plate on which the anti-bacterial action of penicillin was first observed by Fleming in 1928. At the top is a large penicillin colony; below it are colonies of staphylococci in various stages of degeneration under the influence of the penicillin.*

perimentally. The fact that the invading spores destroyed the bacteria with which they came into contact led Professor Fleming to investigate their properties. He found that broth in which they had been grown at room temperature had remarkable power in the destruction of many of the more common pathogenic bacteria, outstanding among these being the pneumonia bacillus and the staphylococci and streptococci which are present in most of the common forms of septic infection. By experiment, Professor Fleming found that the mould-containing broth, injected into the veins, produced no more ill effects than did the injection of plain broth, nor did it set up irritation or any other harmful reaction when applied to the eyeball or to raw and ulcerated surfaces.

All these researches and discoveries were made as long ago as 1930 and 1931; and it is remarkable that no greater use was made of the knowledge then gained, and that no real attempt to apply the new discovery to actual surgical practice was made until the outbreak of war in 1939. In particular, no method had been devised for the separation of the active material from the culture medium in which it was grown.

In August, 1940, a paper was published in *The Lancet* reporting the results of research by a group of scientists working at Oxford. In this paper the authors, who confirmed and extended the discoveries made earlier by Fleming, stated that they had succeeded in preparing from the culture medium a brown powder, soluble in water, effective in the controlling of certain infections. Although these early preparations were relatively crude, and were afterwards shown to have contained as little as from one to two per cent of pure penicillin, the anti-bacterial power of the substance is so great that this group of workers was able to show conclusively the wide range of its activity, as well as its harmlessness and freedom from toxic effects except to bacteria sensitive to it. By further work, they succeeded in obtaining another powder, yellowish in hue, containing up to five per cent of the pure substance. They were able to establish its very slight harmfulness to tissue cells; and they discovered

that it had certain properties which distinguished it from such substances as the sulphonamides. Thus penicillin is active at a much higher dilution than are the sulphonamides, its action is very little affected by the number of bacteria with which it has to deal, and it remains fully active even when the area to which it is applied is contaminated by blood, pus, serum or digestive fluids.

Investigation is still actively going on, although the drug is already in full use in fields where it is found to be beneficial. It is, however, no cure-all; and so far, its use has been limited—even in cases where, in the laboratory, it has been found to kill the germs of certain diseases—by the difficulty—the impossibility in some cases—of bringing it into contact with the germs in their lairs in the human body. For example, penicillin has been found destructive to the bacteria which accompany meningitis; but whereas, when injected, the drug was found in the blood and the urine, and was excreted in the bile, it was found only in a trace in the saliva, and not at all in the tears, the pancreatic juice or the cerebrospinal fluid. Thus the failure of penicillin to penetrate into this latter fluid greatly limits at present its usefulness in the treatment of meningitis.

A Selective Drug

Penicillin is what is called " highly selective "; that is, some species of bacteria are very susceptible to its action, while others are almost unharmed. Some groups which are susceptible are those associated with boils and carbuncles; with sore throat, wound sepsis and puerperal fever; with pneumonia; with tetanus, diphtheria, anthrax, gonorrhœa and, as has been said, meningitis. It is administered in a number of ways appropriate to the effect desired and to the locality to which application is directed. It is injected into the muscle-tissue, either at intervals, or by a continuous gentle flow. It is injected into a vein by either of the above methods, and into other parts of the body by rather elaborate surgical technique. It is also applied locally, and this is the method which has chiefly been used in the treatment of war wounds.

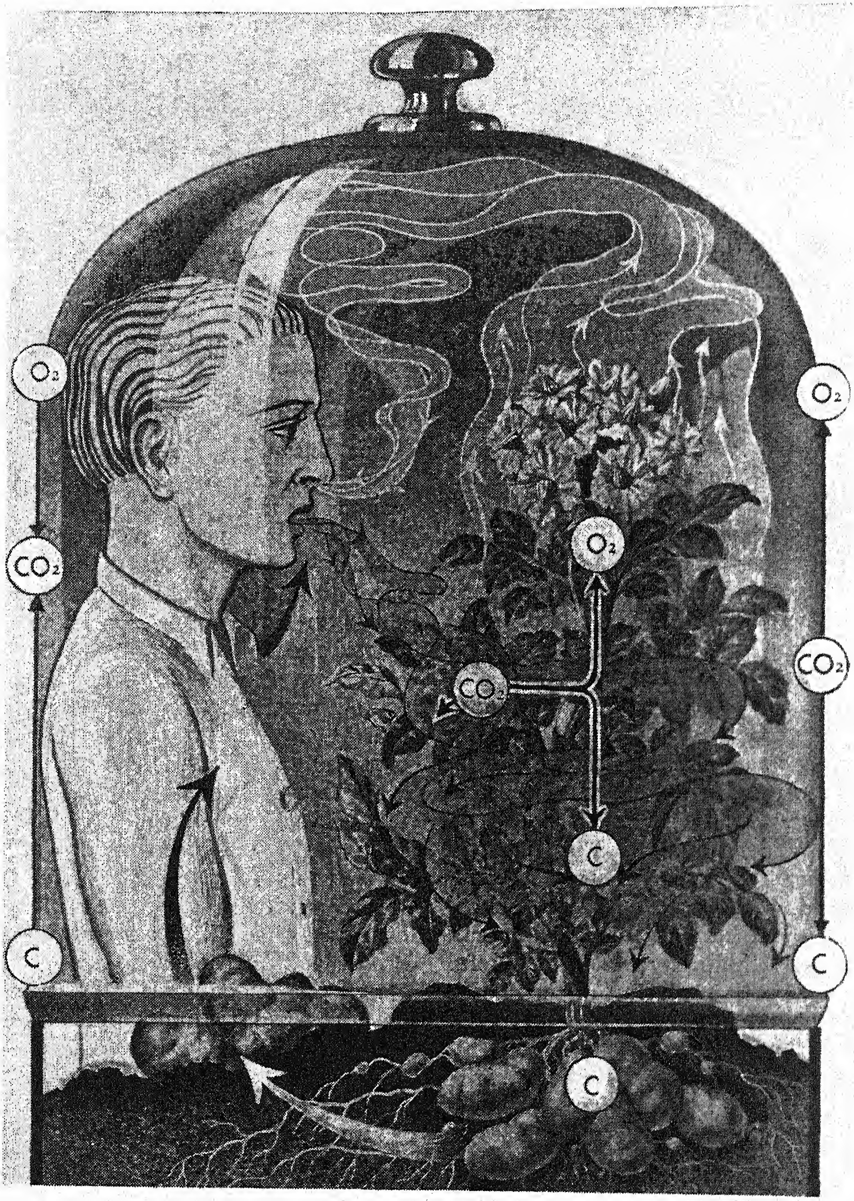
Administering Penicillin

For instance, solutions of the drug are introduced into deep wounds by means of a simple tube, while in surface wounds, a special powder—a mixture of penicillin and one of the sulphonamide drugs—is blown on to the whole affected area. These surface wounds, as well as burns, are also treated with creams containing the drug.

Streptomycin. But even the sulpha drugs and penicillin, which have saved thousands of lives, do not end the story, for a newer drug called streptomycin has been synthesized. This is said to be effective in cases where penicillin and the sulpha drugs are not. It is certainly very promising, and so far as they have gone, the experiments and trials have disclosed few limits to its power of killing disease germs.

In Toronto streptomycin was tried out on 66 soldiers suffering from severe infections of the urinary tract. They were each given a dose, and within twenty-four hours all the harmful germs were killed.

In animals, too, streptomycin has proved very effective in dealing with cases of tuberculosis; but it does not necessarily follow that it will provide a cure for tuberculosis in man.



HOW ANIMALS AND PLANTS EXCHANGE VITAL GASES

FIG. 149. *The cycle of gaseous interchange. Man and plant can live under the same glass bell-jar! Man inhales oxygen (O_2) and exhales carbon dioxide (CO_2). The plant, however, breathes in carbon dioxide, from which it removes the carbon in order to combine it with water to make the sugar and starch afterwards utilized by man as food. The oxygen liberated by the plant returns to the atmosphere, whence it is inhaled again by man.*

V: RESPIRATION

CHAPTER XV

The Respiratory Gases

THE NITROGEN OF THE AIR—THE TRAGEDY OF MANKIND. THE NITROGEN MYSTERY AND ITS SOLUTION. OXYGEN. LIFE AT ALTITUDES ABOVE 13,000 FEET. CARBON DIOXIDE. CARBON MONOXIDE. CAR SICKNESS. THE WATER VAPOUR OF THE AIR.

MAN walks about at the bottom of an immense ocean of air, the atmosphere surrounding the earth. At the bottom of this ocean man lives like a deep-sea fish in the depths of the Atlantic Ocean. The air is a mixture of various gases, consisting of about 79 per cent nitrogen, 20 per cent oxygen, 1 per cent rare gases such as argon, helium, and neon, and 0.3 per cent carbon dioxide, with traces of ammonia and other impurities. Both nitrogen and oxygen are colourless and tasteless gases. Man needs 8 grammes (about $\frac{1}{4}$ oz.) of nitrogen daily, since protein is a nitrogen compound and the body uses up 50 grammes of protein daily which must be replaced.

Since protein is needed to build protoplasm, no creature can live without nitrogen. An animal can be over-fed with foods lacking in nitrogen, such as fat, sugar, and starch, yet it will die because it cannot build up its necessary proteins. On the other hand, a dog can be kept alive on a diet consisting exclusively of amino acids, the nitrogenous compounds from which proteins are constructed, because fats and carbohydrates, the two other chief constituents of the body, can be formed from protein.

The quantity of nitrogen contained in the atmosphere surrounding the earth is immense. It has been estimated that the air over the city of London contains sufficient nitrogen to make 12 thousand million tons of saltpetre. With this quantity the nitrogen needs of the world could be satisfied for several thousand years. But neither plants nor animals nor man can use atmospheric nitrogen to supply the needs of the body; truly, one of the most remarkable facts of natural history. Nitrogen is an inert element which does not enter freely into combination with other elements or compounds. Just as a shipwrecked person, floating about on the ocean, may die of thirst in the midst of immense quantities of water because the body cannot use sea water, so we, living as we do at the bottom of an ocean of air and inhaling 60,000 cubic inches of nitrogen daily, cannot utilize one ounce of it even though it is as essential for us as fuel for a stove. One of the

greatest evils in the world is hunger. Billions of plants and animals go hungry and starve to death every year because they lack nitrogen. Countless human beings have starved to death, and at this very hour thousands are hungry and haven't enough to eat. All of them are hungry for nitrogen, for protein, the dearest of all foods, and yet they stand at the bottom of a nitrogen ocean. This is probably the greatest paradox of terrestrial life, and at the same time the greatest tragedy of mankind.

The Nitrogen Mystery and its Solution. Fundamentally life is a reciprocal robbery of nitrogen. Man eats animals, and animals feed on plants. The plant is the ultimate source of nitrogen for all animals. Stock-farming and agriculture are nitrogen-producing industries. Each grain of wheat is a small box filled with nitrogenous food, each pea a little sack filled with nitrogen, and every fruit a jar containing sugar and nitrogenous protein in its juice.

Nitrogen of the Soil

Where do plants get nitrogen? If a plant is set out in earth lacking nitrogen, it starves to death. The plant obtains its nitrogen from the soil in the form of nitrates. The quantities which it removes from the soil are enormous. A wheatfield of 2.5 acres removes 220-660 pounds of nitrogen annually from the earth. The soil must replenish its supply, for if plants should rob it of its nitrogen, and the latter were not replaced, the soil would soon be so impoverished that not even a blade of grass could be found on the earth. Plants are not the sole factor in the impoverishment of the soil. Water in the form of rains, springs, and rivers also washes the nitrates out of the earth. It has been estimated that rivers carry 88 thousand million pounds of nitrogen into the oceans annually. On the basis of these facts one would have to conclude that this loss of nitrogen impoverishes the soil, and that the oceans become saturated with nitrogenous salts, just as has happened with ordinary sea salt. Actually, however, there is a nitrogen equilibrium in nature.

Root Nodules

The mechanism by which this equilibrium is maintained remained a mystery until an apparently insignificant observation revealed the solution. Farmers have long known that the fertility of a soil can be increased by the growth of almost any leguminous crop. The production of such a crop is accompanied by an actual increase of nitrogen in the soil in which it is grown. It was observed that the power of legumes, such as lupines and beans, to enrich soil with nitrogen was due to the presence of small nodules on the roots [Fig. 150 (B)] and that these nodules were infectious in origin. Thus beans grown in sterilized sand grew very feebly unless nitrogenous materials were added to the sand. These plants were also free of nodular infection.

If, however, an infusion of the nodules obtained from the roots of another plant was added to the sterilized sand, the beans grew luxuriantly and developed nodular excrescences on their roots. When they were removed from the sand it was richer in nitrogen than it had been at the beginning of the experiment. Examination of the nodules revealed that they consisted for the most part of bacteria. These bacteria live as parasites on the roots of leguminous plants, and feed on the protein of the

plant roots. Yet they are by no means simply lazy parasites. They have a definite occupation, since they are able to bind and assimilate the free nitrogen of the atmosphere. In the course of a summer a colony of these bacteria can transform 0.17 ounce of atmospheric nitrogen into nitrates. The plant absorbs these nitrogen compounds through its roots, but it is unable to use all the material manufactured by the nodules. In consequence the excess remains in the soil, thus enriching it with nitrogen. Since the nitrogen bacilli have a predilection for the roots of leguminous plants, members of this group, such as lentils, peas, and beans, have the highest protein content and the greatest nutritive value of all plant foods. Nitrogen bacilli live not only in the roots of legumes, however, but also in a great variety of soils. These organisms can bind free atmospheric nitrogen itself, thus gradually enriching the soil. Nitrogen bacilli are also to be found in the ocean [Fig. 150 (C)]. Their function is exactly opposite to that performed by the bacteria of the soil. Unlike their brothers on land, they do not bring atmospheric nitrogen into combination to form nitrates, but instead they split up nitrates, liberating the nitrogen contained in these compounds. Thus the nitrogen which had been carried into the ocean is returned to the atmosphere.

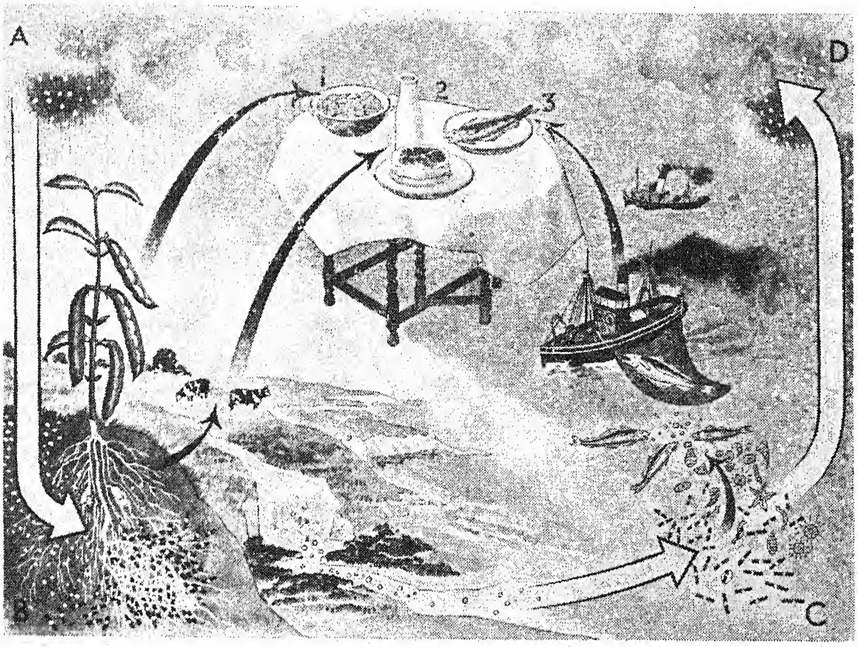


FIG. 150. *The nitrogen cycle in nature. (A) nitrogen of the air; (B) nitrogen-fixing bacteria of the soil and certain plant roots, leading to the nitrogenous products of agriculture (1) and stock-raising (2); (C) bacteria that decompose nitrates in the ocean, thus providing nitrogen for the plankton, the principal food of fishes (3); (D) return of nitrogen to the atmosphere.*

These bacteria are eaten by the creatures of the oceanic plankton, and the latter in turn are eaten by small crabs, snails, and worms. Fish feed on these animals, and the fish themselves serve as food for man [Fig. 150 (3)]. On land man grows plants that obtain nitrogen from the soil, in the ocean he catches fish in which the nitrogen treasures of the ocean have been stored—it is evident that life is a continual hunt for nitrogen. And, at bottom, man lives by the grace of a bacillus which is so small that the human foot cannot crush it even when it steps on it.

Oxygen. In contrast to nitrogen, oxygen is chemically very active. Most compounds in the earth's crust contain oxygen; $\frac{8}{9}$ of the weight of water, more than 50 per cent of the weight of the earth's crust, and more than 50 per cent of the weight of a human being are due to oxygen. The rapidity with which oxygen attacks other compounds is phenomenal. It smashes a molecule and combines with the fragments. This process is described as oxidation.

Energy Waves

Cut an apple or a potato in two and observe the cut surface. After a while it turns brown because the oxygen of the air acts upon the exposed molecules and breaks them up into simpler compounds possessing a brown colour. In the course of the oxidizing process the atoms acted upon vibrate and emit energy waves which impinge upon our senses as heat, and if the vibrations are shorter and more rapid, as light. An oxidizing process characterized by the development of light and heat is known as combustion. Fire is produced by the union of oxygen atoms with the molecules of a fuel substance. Fuels are substances which unite so rapidly with oxygen that heat and light waves are produced. Light a candle. In the burning wick oxygen is uniting with the fat molecules of the candle. Now cover the candle with a glass jar. The flame becomes smaller, and as the last oxygen atoms from the atmosphere of the microcosmos under the glass jar are used up, the light is extinguished. Fire is a cosmic conflagration and destruction in the molecular microcosmos.

The Human Furnace

Man is a machine which functions because of the "desire" which oxygen has to unite with other elements. Man takes oxygen and fuel substances into his body, where oxidation takes place, producing heat. This heat makes human life possible. The intake of oxygen is called respiration; that of fuel, nutrition. The oxidizing processes in the human body do not take place slowly as on the cut surface of a potato, or as rapidly as in the burning candle, but at an intermediate rate, thus producing a body temperature of 98.6° Fahrenheit. The human body is warm because combustion (oxidation) takes place in it; and this latter process occurs because it breathes. A breathing human being is a continuous furnace in which the carbon of the ingested food is slowly and uninterruptedly consumed throughout life by the oxygen of the inspired air at a constant temperature of 98.6° Fahrenheit. A diagrammatic representation of this process is depicted in Fig. 112 (I) and described on pages 139-140.

Life at Altitudes above 13,000 feet. The greater the distance from the earth, the more rarefied does the atmosphere become and the smaller its

oxygen content. In 1862, the Englishmen, Coxwell and Glaisher, ascended to a height of 37,000 feet in a balloon, at Wolverhampton, and scored an altitude record which has never been beaten in an open car without special breathing apparatus. Glaisher noted that his pulse, which beat at 76 per minute at starting, rose to 90 at 10,000 feet, 100 at 20,000 feet, and 110 at about 25,000 feet. Both balloonists suffered from bleeding at the nose and ears, and were exposed to a temperature of $-100°$ Fahrenheit. Glaisher became temporarily blind, and at 29,000 feet fell unconscious. Were it not for the exceptional stamina of Coxwell, both the aeronauts might have lost their lives.

In 1875 the balloon Zenith, with three scientists aboard, ascended from Paris and rose at once to a height of 24,430 feet. One of the three balloonists, Tissandier, noted: "Crocé is gasping for breath, Sivel is dazed, but can still cut three sandbags loose in order to reach 26,000 feet." Then Tissandier himself was overcome by a fit of hilarity, as if he had become intoxicated [Fig. 152 (a)]. He tried to call to his friends, but his voice failed. He lost consciousness and did not awake again until the balloon was descending. They had attained a height of approximately 28,000 feet; but two of the scientists lay dead in the gondola of the balloon. The air at great heights does not contain enough oxygen to support life.

Having trained himself for activity at high altitudes, Colonel Norton was able to attain a height of 27,800 feet on Mount Everest without using an oxygen inhalation apparatus. Nevertheless, he was unable to cover the last 1,100 feet to the summit. The air at these heights contains too little oxygen to support the oxidizing processes that are necessary for the vital

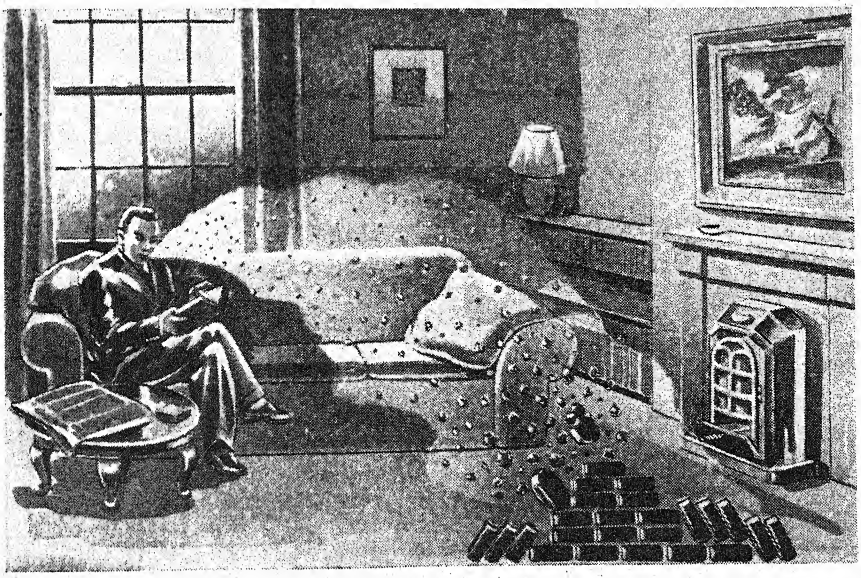


FIG. 151. *The carbon dioxide exhaled by a single human being in the course of a year may contain as much carbon as one thousand briquettes.*


ZENITH
1875
a
28,000 FT.
27,800 FT.
b
c
23,000 FT.

HOW MAN BEHAVES AT GREAT HEIGHTS

Fig. 152. *At an altitude of approximately 20,000 feet the functioning of the human machine becomes complicated by serious difficulties—physical, mental and psychological—owing largely to the rarity of oxygen in the atmosphere at such elevations.*

(a) The ascent at Paris of the balloon "Zenith" in 1875 terminated tragically with the death of two of the balloonists upon reaching an altitude of about 28,000 feet, because, as a result of mental confusion, they failed to make use of the safety appliances with which they were equipped.

(b) The greatest altitude achieved on land without the use of oxygen was attained by Lt.-Col. Norton, an Englishman, with a height of about 27,800 feet, during the attempt on Mt. Everest in 1924. He was unable to travel farther because his mobility had diminished to such an extent that he required an hour to traverse 275 feet of normal terrain ("slow-motion" gait).

(c) In the course of scientific experiments in pneumatic chambers where the air is rarefied to correspond to an altitude of 23,000 feet, the subjects exhibit attacks of frenzy or apathy.

(d) Modern stratosphere flights up to heights of 74,000 feet are carried out in closed gondolas within which normal atmospheric conditions are maintained by the use of oxygen. Without such aids, life becomes impossible at a height of about 29,500 feet.

(e) The "Indios" who work in the Andean copper mines at altitudes of 20,000 feet are the only race in the world who dwell and work at such heights.

working of the body. When acclimatization is gradual and individuals do not exert themselves, they are able to maintain themselves in such a rarefied atmosphere. The slightest exertion, however, such as opening a can or changing from a lying to a sitting position, causes extreme breathlessness. Seven to ten breaths are necessary in order to take one step! Norton took one hour to ascend 275 feet of easy terrain at this altitude (b).

In a rarefied atmosphere an individual can move only in slow-motion tempo. Yet the greatest danger is not breathlessness, or the difficulties of respiration, but rather the mental confusion into which people at high altitudes are thrown. They become careless, indifferent, and intoxicated, or quarrelsome and irritable. There were oxygen-containers in Tissandier's balloon, but owing to their mental confusion, his companions were unable to open them. At altitudes above 16,000 feet completely unmotivated quarrels break out among friends, just as they do among drunken men. High-principled, honest athletes begin to brag, talk nonsense, and wave their arms about—at an altitude where every unnecessary motion must be avoided!

Artificial Altitude Conditions

In modern research institutes the effect of high altitudes on the body is studied in pneumatic chambers (c). The air within such an apparatus can be rarefied so that it corresponds to conditions found at different altitudes. At heights over 19,500 feet in these chambers individuals exhibit states of excitation which sometimes develop into attacks of frenzy. The increased oxygen starvation of the brain also produces failure of judgment and inability to co-ordinate muscular movements properly, so that a man may no longer be capable of taking up a pencil. "Most high-altitude catastrophies are tragedies of paralysed volition."

Individuals vary greatly in their sensitivity to altitude. Up to about 13,000 feet no marked changes are noticeable. Then the symptoms of mountain sickness begin to appear: attacks of breathlessness, suffocation, severe headache, nausea or vomiting, confusion of thought, and a feeling of fullness in the upper abdomen.

Mountain Sickness

Most people gradually recover from mountain sickness if they remain at a given altitude. By means of its internal regulatory mechanisms the body adapts itself to the changed conditions. If the individual moves to a different altitude, new attacks may follow, and ultimately the limits of the process of adaptation are reached. An individual will tolerate conditions at high altitudes better the more time he allows his body in which to adapt itself. An adapted person is 6,500 feet ahead of one whose body is not adapted to high altitudes; that is, the former's body behaves at 23,000 feet as the latter's does at 16,500 feet. The absolute limit of adaptation is reached at 29,500 feet, above which life is impossible unless oxygen tanks or sealed aeroplane cabins are employed, as in stratosphere flights (d).

Carbon Dioxide. Inhaled oxygen (O_2) combines in the body with carbon (C) derived from the ingested food to form carbon dioxide (CO_2) [Fig. 112 (II)]. This gaseous compound is excreted through the lungs. An individual exhales about 1,200 to 2,400 cubic inches of carbon

dioxide in an hour, and 30,500 to 61,000 cubic inches in the course of a day. The latter quantity contains approximately as much carbon as two to three bituminous coal briquettes. In the course of a year a breathing individual could accumulate a supply of 1,000 briquettes if he were able to save and utilize the carbon dioxide that he exhales [Fig. 151].

Like man, all forms of combustion machines—candles, lamps, furnaces, steam engines, locomotives, automobiles—give off carbon dioxide. A metropolis exhales many million litres of carbon dioxide daily. At present the normal content of the atmosphere is 0.03 per cent; in cities it rises to 0.1 per cent and more. Carbon dioxide is poisonous. In an atmosphere containing 7 per cent carbon dioxide respiration becomes gasping, and when a concentration of 14 per cent is reached, man dies. It is also a very heavy gas and in rooms carbon dioxide in the air sinks to the floor.

Nature's Insulation

Carbon dioxide is a poor conductor of heat. We owe the temperature of the earth's surface to the inclusion of this gas in the atmosphere surrounding the earth. Without the covering atmosphere which surrounds it, the temperature of the earth's surface would be 12° Fahrenheit. The atmospheric cover prevents a heat loss of 68°. Some scientists suggest that slight variations in the carbon dioxide content of the atmosphere caused the Ice Ages, during which the average temperature varied but a few degrees.

The carbon dioxide exhaled by men, animals, and machines is taken out of the air by plant leaves [Fig. 149]. The chlorophyll granules of plants, whose green pigment is closely related to the red pigment of the blood, split the carbon dioxide by means of sunlight. The plant gives off the oxygen (O_2) to the air, and the carbon (C) unites with water (H_2O) to form sugar, $6\ (C.H_2O) = C_6H_{12}O_6$, and starch, $12\ (C.H_2O) = C_{12}H_{24}O_{12}$.

Vegetable Dynamos

Together, plants and animals keep the scale of life in balance. Plants are dynamos which under the influence of sunlight charge the batteries of the cells with energy in the form of highly charged starch molecules. Man places these batteries in his body-car and goes for a drive by means of their power. A human being can be placed under a glass jar together with a plant. If the sun is permitted to shine on it, the mechanism begins to function. Man exhales water vapour and carbon dioxide; the plant takes these two substances and with the aid of the sun's rays prepares starch, potatoes, or other products from them. The plant exhales oxygen. Man receives both the food and the respiratory gas and burns them in his body, exhaling carbon dioxide and water. This *perpetuum mobile* is terrestrial life.

Carbon Monoxide. Carbon monoxide (CO), which in contrast to carbon dioxide (CO_2) contains only one atom of oxygen, is formed wherever there is not enough oxygen for carbon to be completely consumed to CO_2. It is contained in illuminating gas, and is formed as a result of premature closure of furnace valves, by fires in closed rooms, in mine shafts, and as a result of incomplete combustion of petrol in an automobile motor. Theoretically the petrol

should be completely consumed, forming carbon dioxide and water. If the motor runs smoothly, this is to a large degree the case. In urban traffic, however, owing to slow driving and the frequent stopping and starting of the motor, some of the petrol is only partially consumed, thus forming CO. In modern cities several hundreds of thousands of quarts of carbon monoxide are blown into the air daily from automobile exhausts. Carbon monoxide is extremely poisonous. Oxygen already has a marked affinity for blood pigment. The concentration of oxygen is sixty times greater in a blood cell leaving the lungs than it is in the respiratory air. Carbon monoxide surpasses oxygen one hundred and forty times in this respect! On coming in contact with the blood pigment carbon monoxide destroys it. It forms an insoluble compound with the pigment, rendering it permanently useless for the transportation of oxygen. At each breath of air containing carbon monoxide, millions of blood cells are occupied and captured as if by a cunning foe. The respiratory fleet of 22 to 25 million million blood cells is decreased by the number of captured cells. Air containing more than 0.02 per cent of carbon monoxide is injurious to health; a greater content is dangerous or even deadly.

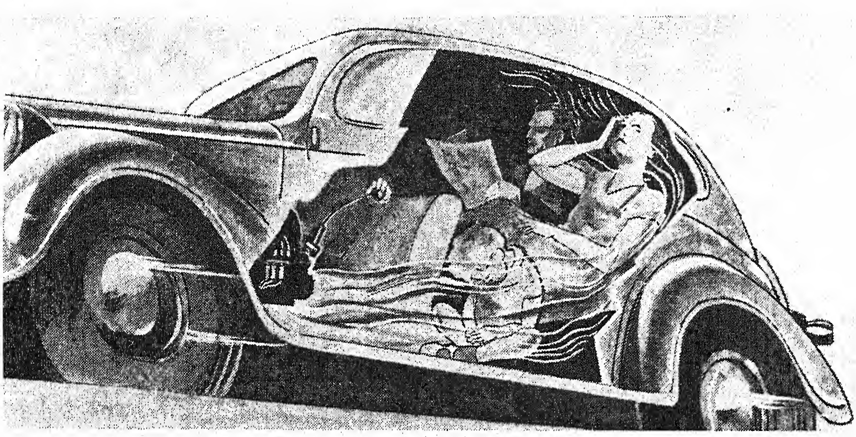


FIG. 153. *Car sickness. The exhaust gases of a motor car contain the poisonous, odourless gas carbon monoxide. When the engine is running a certain amount of this gas accumulates in the car, particularly along the floor. Car sickness, which produces headache, nausea and numbness, is a form of carbon monoxide poisoning. Children are particularly susceptible, and should not be allowed to sit on the floor of a running motor vehicle.*

Car Sickness. Persons who sit in automobiles for long periods frequently complain of headache, nausea, and a feeling of fatigue, the entire condition exhibiting the characteristics of an intoxication. This "automobile sickness" is due to carbon monoxide poisoning. The air-pressure within a travelling car is decreased, because the strong pull of the air currents created by the moving car sucks some of the air out of the interior. The resulting partial vacuum draws up warm air mixed with exhaust gases, which collects

under the floor of the car [Fig. 153]. The odorous gases are unpleasant, but not so dangerous. All the more dangerous is the completely odourless and invisible carbon monoxide. Children are primarily endangered because they are closer to the floor of an automobile and are more susceptible to the gas. Under no circumstances should children be allowed to sit or lie on the floor of an automobile so long as the motor is running. Nor should a motor be allowed to run in a closed garage.

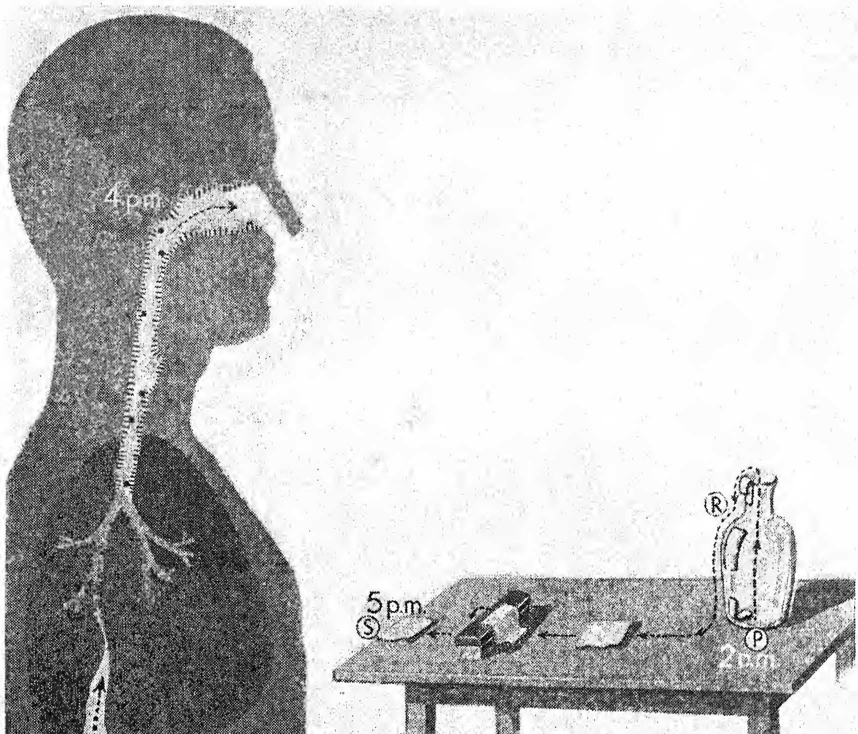
Geographical Influences

The Water Vapour of the Air. The human body is a vessel containing 11 gallons of warm fluid. By means of the lungs this vessel exposes a broad surface—2,152 square feet!—to the outer world, and has a single draughty chimney, the windpipe or trachea. Considerable quantities of water evaporate through the trachea, just as a locomotive filled with warm water gives off steam. If the outer air is warm, we do not see this steam, because the water immediately evaporates. When it is cold, however, the water vapour condenses as soon as it emerges from one's mouth, like clouds in the cold sky. The air contains varying quantities of water vapour, depending on the geographical location and the weather, which affect our health considerably.

Dry Air Healthier

Sea winds and cyclones crossing the Atlantic from America to Europe carry moisture. As a result countries such as England and Holland, situated directly on the route along which most cyclones cross the Atlantic, have a particularly moist climate. A similar situation exists in those parts of the northern Alps where the routes of the weather cyclones cross the mountains, and the accompanying rain clouds meet the mountain walls and lose their water in the form of rain. Districts on the shadow side of the mountains such as the Ticino, or far inland like the Russian steppes, are dry.

In general people feel more comfortable in a dry atmosphere than a humid one. In a humid atmosphere the body loses less water vapour, and water collects in the tissues. Owing to the decreased evaporation of water from the body in humid air, the body is not cooled as much, its heat accumulates, and the body temperature is increased in consequence.



NATURE'S VACUUM CLEANERS

FIG. 154. *The respiratory tract, from the nose as far as the lungs, is lined with ciliated cells. The minute cilia whip to and fro unceasingly, like a wheat-field in the wind, and in doing so they remove dust from the air passages. Dust introduced into the lungs appears in the nose two hours later. A piece of ciliated tissue will creep out of a bottle and travel over obstacles (P—R—S), under the motive power of the cilia.*

CHAPTER XVI

The Nose

MAN'S AIR APPARATUSES. THE NASAL CAVITY. PHARYNGEAL TONSIL AND ADENOIDS. THE NOSE AS A VACUUM CLEANER. THE NOSE AS A STERILIZER. REMOVING DUST PARTICLES. THE REFLEX AND COLDS.

IN order to accommodate itself to the atmosphere in which it lives, the human body has developed a number of air apparatuses: the respiratory apparatus, which inhales air from the atmosphere, removes the oxygen from the inhaled air, and exhales the waste products; the respiratory centre in the brain, which regulates the gas content of the blood and the rapidity of respiration; the temperature corpuscles of the skin, which measure the temperature of the air; the hair of the body, which makes us aware of draughts; the sweat glands, whose activity is adapted to the varying water-vapour content of the air; the vocal apparatus of the larynx, which produces air waves; and the auditory apparatus in the ear, which registers these air waves as sound.

The respiratory apparatuses consist of the nose, trachea, lungs, diaphragm, and ribs.

The Nose. The first apparatus through which the inhaled air passes is the nose. The structure which we see as the nose in a face is only the anterior gable; indeed, it is actually only a projecting room of the spacious nasal cavity, which occupies the entire central portion of the facial skull as far back as the ear. The chief portion of this "gable" is cartilaginous, for a bony nose tip would break off as easily as the spout of a teapot, leaving a mutilated face [Fig. 155]. Nothing determines the impression made by a face as much as this projecting nasal structure. Children appear pretty to us because the form of their noses is not yet distinctly developed. In consequence they are not so frequently disfigured by ugly noses as adults.

A nose projecting out of the face is a specific characteristic of man. No animal has a projecting nose, nor did the earliest prehistoric man have this feature well developed.

The Nasal Cavity. The nasal cavity is one of the most versatile and, because it is so easily accessible from outside, one of the best investigated organs of the human body. Its task is the general preparation of the respiratory air for inhalation into the lungs. As a result of the activity of the nose the lungs always receive the same warm, moist air, cleansed to some extent of dust and germs, no matter whether the air outside is cold or warm, dry or humid, dusty or clean. In the nasal cavity the outer air of the atmosphere is transformed into the air of the respiratory apparatus.

The Nose as a Traffic Regulator of the Respiratory Air. First of all, the inhaled air must be subjected to the traffic regulations of the nose. It must

flow along certain paths. Since the nasal orifices open downward, the air must rise upward and describe a broad arc in the upper part of the nasal cavity. It must remain in the nasal cavity for a long time, and pass all the stations where the air is subjected to various treatments. If a person loses the tip of the nose, the inhaled air does not rise upward, but instead is wafted directly backward. Since the olfactory area is situated in the upper part of the nose, and the stream of air no longer rises upward, the individual loses his olfactory sense along with the tip of his nose.

Warming the Air We Breathe

The Nose as a Steam-Heating System. On its way the air passes a number of scroll-shaped, overhanging structures projecting from the lateral walls of the nose, and known as the nasal conchæ. The conchæ are heating apparatuses, since they are traversed by blood vessels that radiate heat like hot-water pipes, thus warming the respiratory air. On its way from the nostrils to the pharyngeal tonsils the temperature of the air rises more than 30°. The conchæ not only heat, but also steam the inhaled air. Warm fluid exudes from numerous glands and lymph spaces, evaporates in the warm interior of the nose, and saturates the passing respiratory air with water vapour. In addition there is still another steam apparatus, the tear-dropper. In the wall of the orbital cavity is the tear gland, which moistens the eye. The tear fluid covers the surface of the eye and flows into the nasal cavity through the lacrimal point and canal situated in the inner corner of the eye. The fluid falls on the inferior concha, which is warm and it causes it to evaporate rapidly so that the steam rises upward like a geyser [Fig. 156].

Pharyngeal Tonsil and Adenoids. After the respiratory air has passed through the nasal cavity it meets the posterior wall of the pharynx and passes along the pharyngeal tonsil. This structure is composed of spongy lymph tissue, and like the palatine tonsils frequently hypertrophies during childhood. Hypertrophied pharyngeal tonsils are known as adenoids. Children who have adenoids exhibit characteristic symptoms. Since the adenoid growths block the nose, these children breathe through the mouth. A dull facial expression, open mouth, pinched nose, and a dead toneless voice all point to adenoids. These children are restless in their sleep, snore, and wake up frequently. As a result they are tired and listless in the morning and do poorly in school. Their memories are bad, and they do not progress in their studies. Because of the nasal obstruction these children have little appetite, eat poorly, and are undernourished. This is especially true of younger children.

A Cause of Backwardness

Where there has been a condition of marked nasal obstruction for a long time, children often develop a high arched palate. Not only are these children cruelly treated by nature, but, what is even worse, very often by their uncomprehending milieu. At school they receive poor marks, and at home they are scolded and have their ears boxed because they eat poorly, or because they forget to buy something for which they are sent to the shops. Instead of scoldings and punishments such children need cod-liver oil, sunlight, and the removal of their adenoids, whereupon they

usually begin to flourish like potted plants that are removed from a dark corner to a sunny window sill.

The Nose as a Vacuum Cleaner. While passing through the nose, the dust contained in the respiratory air is removed at several different points. The first cleansing is carried out by the bristle hairs at the entrance of the nose [Fig. 156]. Coarse dust particles are removed here. The bristles are situated in the vestibule of the nose; in the nasal cavity proper this lining is replaced by a delicate microscopic layer of ciliated cells. The entire respiratory canal from the nasal cavity to the air chambers of the lungs is covered with cells bearing delicate hairs, called cilia, on their surface.

Creeping Tissue

About a dozen such cilia project from each cell, moving rhythmically back and forth like wheat on a windswept field. During life they are in constant motion, lashing to and fro quickly, twelve times per second. If a piece of the inner surface is removed from the throat of a frog immediately after it is killed, and is examined with a microscope, it presents the appearance of a grain field when the wind blows on it [Fig. 154]. If this preparation is kept and care is taken that it does not dry up, the cells may continue to exhibit the same action for as long as eighteen days. If the piece of tissue is turned over so that the cilia are on the under surface, it begins to creep away, owing to the motive power furnished by the beating cilia. In three hours it has crept off the table, and if an obstacle is placed in its path it creeps over it. Such a piece of tissue is able to creep out of a bottle in which it has been placed. The power which these cells develop is astonishingly great: 0.15 square inch of ciliated tissue has the power required to raise 0.2 ounce $\frac{1}{254}$ inch every minute, and to set a weight of 12.7 ounces in motion. If a ciliated cell were magnified to the dimensions of an automobile and the power of its cilia multiplied correspondingly, this auto-

FIG. 155. *The projecting part of the nose contains no bones, but consists of soft tissue supported by plates of cartilage. A projecting nose is a peculiarity of man.*

cell would have the power required to dash away at a speed of 25,000 miles per hour—that is, to run around the globe in one hour—and to run eighteen days before its internal energy was exhausted.

Removing the Dust from the Windpipe. Each little hair of a ciliated cell strikes with greater force in one direction than in the opposite. Since the direction of each stroke is the same for all the cilia on a surface, it is clear that any object on them will be moved in one direction. In the case of the respiratory passages it is directed towards the outer world

—that is, upwards towards the throat and the nasal cavity. Thus many dust particles that enter the respiratory passages with the inhaled air are removed by way of the nose. Pure nasal mucus is as clear as glass. The greyish-green colour of the nasal mucus is due in part to microscopically small dust granules that are brought up from the windpipe by the cilia and carried into the nose. Anyone who comes home in the evening after a long trip in a sooty railway coach finds the mucus from his nose black with soot. After cleaning the nose until clear mucus appears he thinks he has removed all the soot and goes to bed. The next morning, however, soot once more appears in his nose. This is dust which the ciliated cells have brought up from the depths of the lungs during the night. Ciliated tissue is a "bucket elevator" which works uninterruptedly in the body, carrying inhaled dust from the lungs to the outer world. Every minute a human being inhales several million dust granules. Only the air over the ocean at a distance of more than 600 miles from a coast is dust-free. Even on the peaks of the Alps each breath of air contains 10,000 dust particles. Each breath of pure country air carries half a million dust particles into the human respiratory passages.

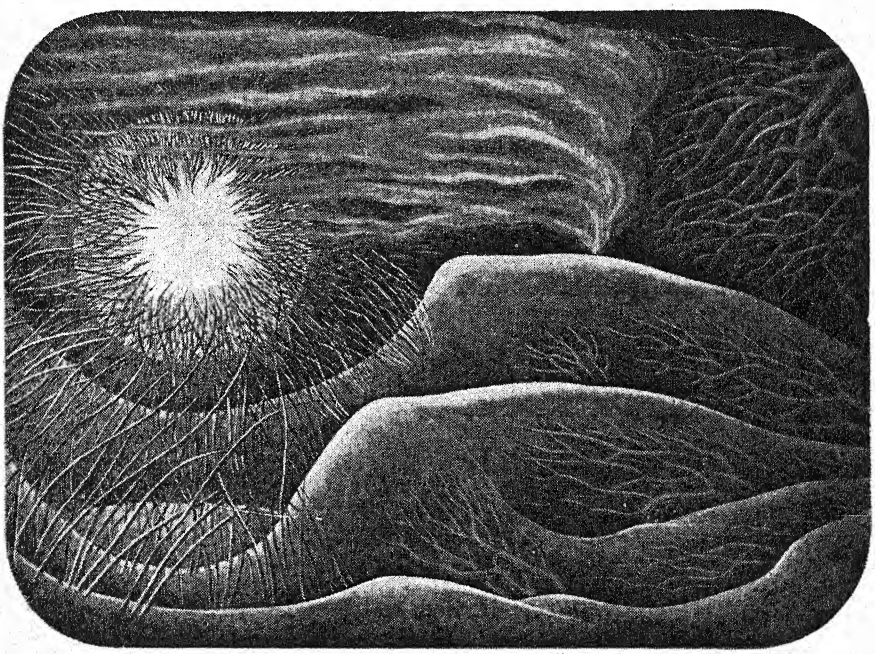


FIG. 156. *Nasal anatomy from within. If we could look down the inside of the nostril from above it would appear like this. The nasal orifice is surrounded by hairs that catch dust particles. The nasal turbinates rise like mountain ranges. Along their walls pass the tortuous vessels that warm the inspired air. The tear fluid which enters the nose evaporates on the warm turbinates; the resulting vapour is represented here in the form of a geyser, amid the weird nasal "landscape."*

Every breath of good suburban air contains 125 million particles, city air at the level of an adult's head about 5 thousand million, and at the level of a child's head 50 thousand million. Several million million dust particles fly about in a room which is kept clean, and if someone smokes in it he adds 4 thousand million more soot particles.

Dangers of Dust

Dust is very light; it takes many billion dust particles to make up a fraction of an ounce. But we breathe constantly and life is long. In the course of a lifetime a modern city dweller inhales about 45 pounds of dust into his lungs, and among workers in dusty trades, such as stonemasons, stokers, miners, cement workers, and grinders of all kinds, this quantity is increased to 100 pounds and more. The lungs of dead persons tell us whether they lived in a coal-mining district or in some other region.

But not every type of dust is injurious to health. The most dangerous of all is silica dust. Persons who work with siliceous rock without adequate protection succumb almost without exception to lung diseases, and occupy a prominent place in all statistical compilations of occupational mortality. Marble is relatively harmless because it is a calcium compound. In no occupational class are there so few workers affected with lung troubles as among those who work with limestone or calcined gypsum.

The Nose as a Sterilizer. Innumerable bacilli enter the nose together with dust. The walls of the nasal cavity are covered by the viscid mucus of the nasal glands. Many dust particles and bacilli stick to the mucous layer like flies to flypaper. Not only is this mucus sticky, but it is also antiseptic.

The Reflex. When we close our eyes on going to sleep we are performing a voluntary act. If a coal particle flies into an eye we must close it immediately whether we want to or not. This closure of the eye is not an "act," but a compulsive movement. The body responds to a stimulus with a reaction without consulting the individual's volition, just as a ray of light is reflected by a mirror. In contrast to a volitional act, this automatic movement is known as a reflex. A reflex is an automatic response by the body to an external stimulus, uninfluenced by the individual's will. The nervous impulse which initiates the reflex does not pass through the brain but through a number of lower nerve centres known as reflex apparatuses.

Asthma and Spasms

Such reflexes may be produced by stimulating various parts of the body, including the nose. If the nasal conchæ are oversensitive to stimuli, they give rise to spastic conditions of various organs — for example, the trachea and the bronchi, producing asthmatic attacks. Morbid conditions resulting from an extreme sensitivity of the nerves without any corresponding pathological state in the affected organs are called neuroses. When neuroses arise because of the disturbance of reflex apparatuses such as the nasal conchæ they are known as reflex neuroses. The nasal conchæ are connected by various nerve paths with many organs in the body, and when stimulated give rise to such reflex neuroses as spasm of the glottis, spasmodic cough, migraine, and epileptiform attacks. These reflex neuroses

can often be cured simply by cauterizing the sensitive spot in the nose.

The Reflex Cold. The reflex pathway from the nasal conchæ to the organs of the body conducts impulses in two directions. If a hot-water bottle is placed on the abdomen, not only does the abdominal skin become red, but the nasal conchæ as well. Conversely an ice bag on the abdomen causes the conchæ to contract. An ice bag on the abdomen is a rather infrequent occurrence, but the sole of the foot frequently becomes "ice cold." Similar stimuli emanate from the sole of the foot. If the feet are warm, the nasal conchæ are well supplied with blood and are warm; when the feet are cool the conchæ become pale and cold. Two sisters go out on a rainy day. One of them puts on goloshes, keeping her feet warm and dry [Fig. 157]. The soles of the feet maintain a temperature of 90°F., the nasal conchæ are well supplied with blood, the inhaled air is mixed with water vapour, the glands produce sufficient quantities of mucus, which kills the inhaled bacilli; the inhaled air is warm, moist, and sterile when it enters the lungs. Nothing happens to the young

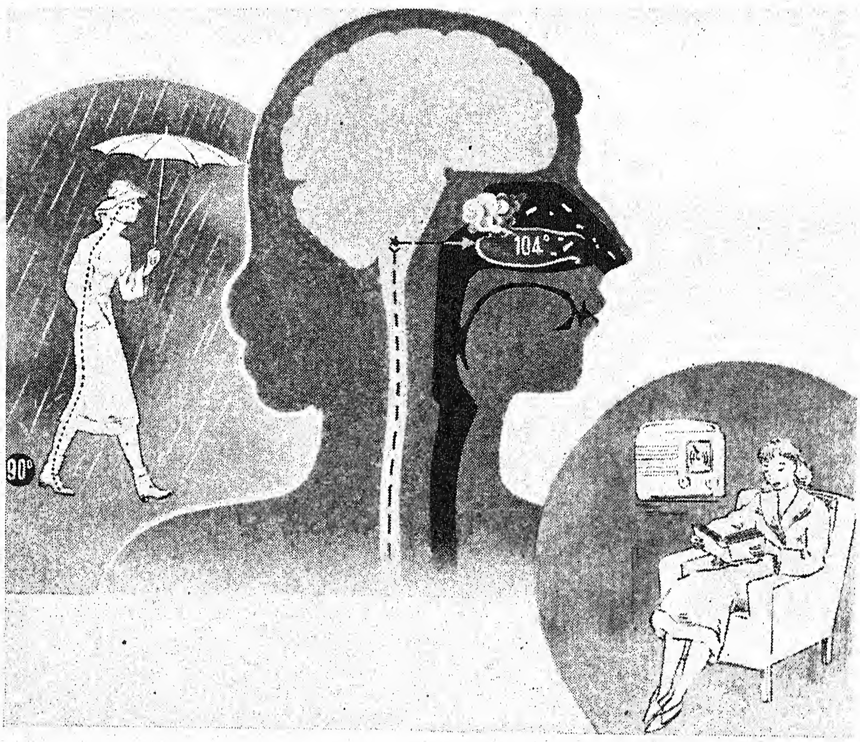


FIG. 157. *Warm feet are a protection against catching cold. The sole of the foot is a reflex apparatus which initiates numerous postural, motor and respiratory reflexes. If the feet are warm, the nasal turbinates are well supplied with blood; they remain warm in their turn and secrete enough mucus to warm and moisten the inhaled air and kill bacilli. Thus the air is moist, warm and sterile by the time it enters the lungs.*

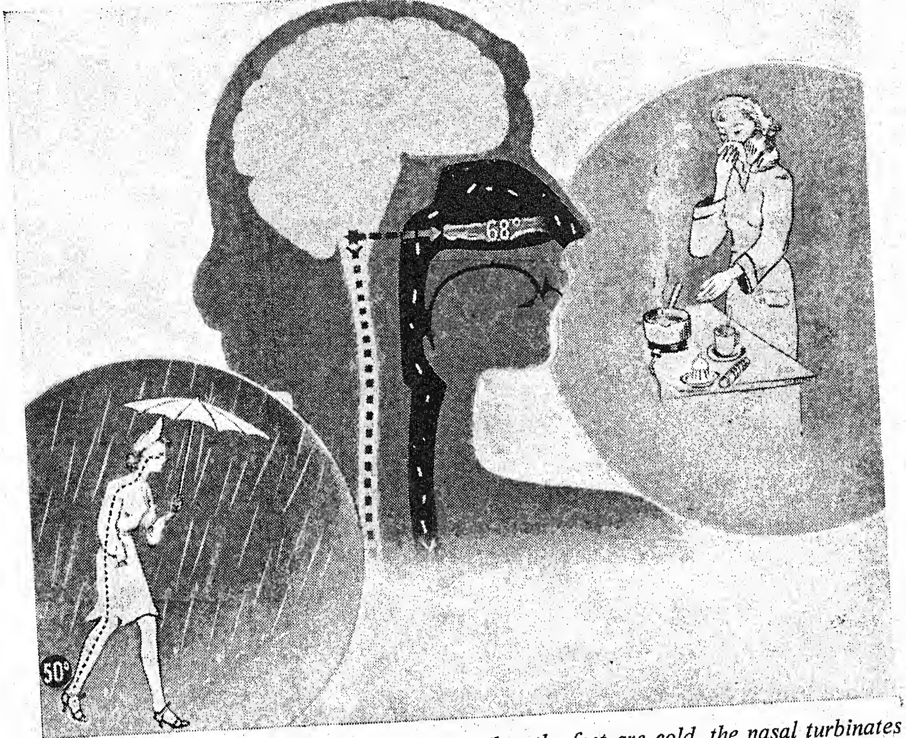
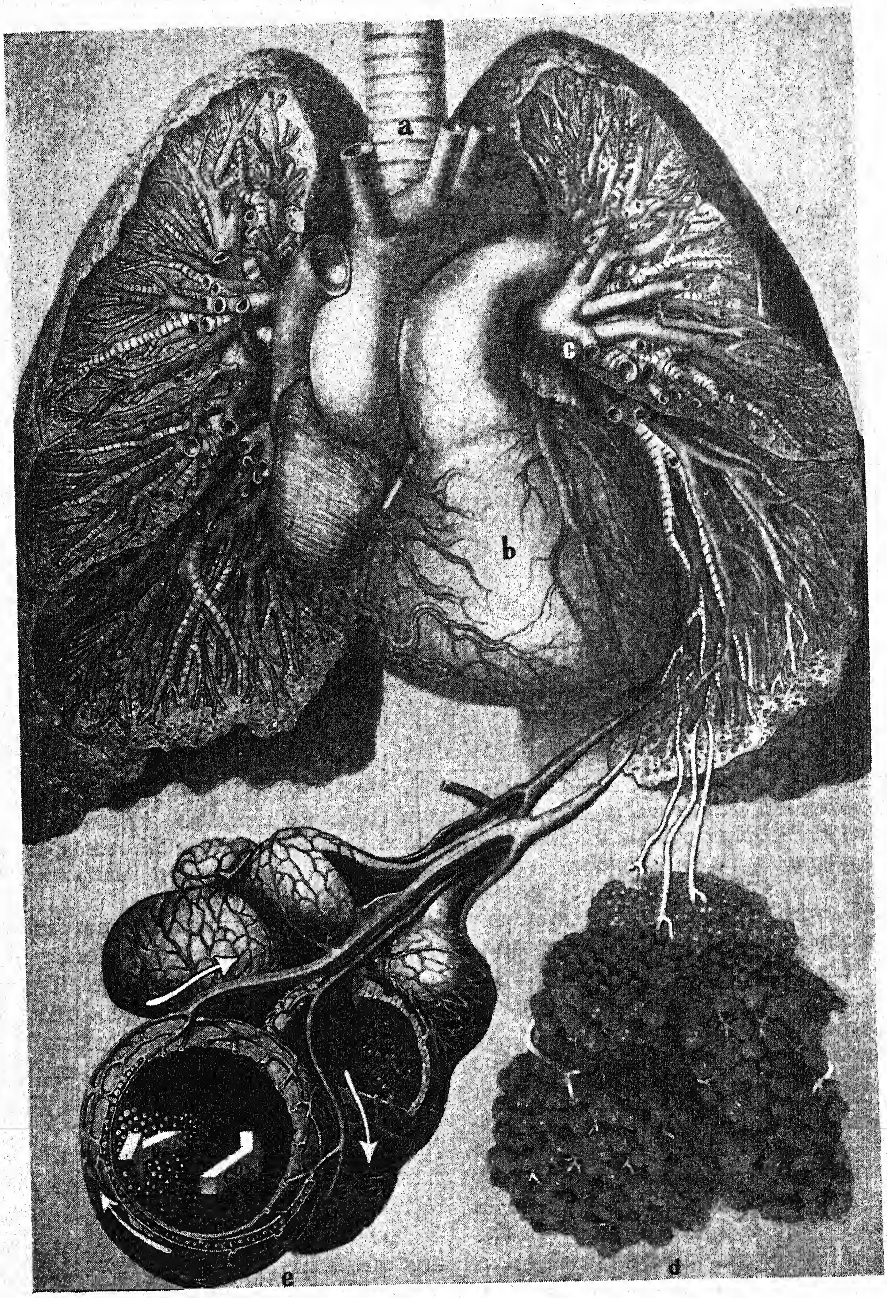


FIG. 158. *Cold feet predispose to colds. When the feet are cold, the nasal turbinates contract and become cold and dry, and the nasal glands stop secreting. A person with cold feet inhales dry air which contains more bacteria than usual. For this reason, he is in greater danger of catching cold than would be the case if his feet were warm.*

girl, who is able to sit comfortably in the evening listening to the radio.

The other sister, however, goes out wearing sandals [Fig. 158]. Her feet become wet and cold, producing strong reflex stimuli that act on the body. The nasal conchæ contract and their blood-supply is impaired so that they become pale and cool. The glands stop secreting and the bacilli are able to advance to the naso-pharynx and flourish there. In the evening the girl has a scratching sensation in her throat and does not feel well. She feels chilly and busies herself making some hot lemonade. She has a head cold and a sore throat because her feet got wet. A " reflex " cold. The consequences of wet, cold feet are not always a head cold or laryngitis, but may also lead to an inflammation of the bladder or the lungs, depending on the sensitivity or constitution of the patient.

The olfactory functions of the nose are discussed in Chapter XXXIX.



THE LUNGS—CHIEF ORGAN OF BREATHING

FIG. 159. *Between the sectioned lungs are seen the trachea (a), heart (b) and bronchial tubes (c). Below is the bronchial "tree" under (d) low and (e) high magnification.*

CHAPTER XVII

The Lungs

TRACHEA AND GLOTTIS. THE RESPIRATORY CHAMBERS. ASTHMA AND EMPHYSEMA. THE PLEURA. THE GASEOUS EXCHANGE. MAN DOES NOT SINK IN WATER! THE RESPIRATORY CENTRE.

FROM the nasal cavity the inhaled air is conveyed to the lungs through the trachea or windpipe [Fig. 159 (a)]. This structure consists essentially of a membranous tube about 4 inches long in which annular cartilages are embedded so that it will not collapse. At the upper end of the trachea is the larynx or voice box. The vocal organ is situated between the trachea and the root of the tongue, and presents the form of a triangular box flattened behind and at the sides. It is composed of cartilages connected by ligaments and moved by numerous muscles. The interior of the larynx is divided into two parts by the vocal cords, between which is a narrow triangular slit, the glottis. The glottis is the watchful entrance to the trachea, which can be closed whenever necessary. At the slightest touch it closes the trachea against the outside world.

Nature's Defence

Not only is the glottis exceedingly sensitive to inhaled dust particles or swallowed fishbones, but also to irritating gases. Even if we want to, we cannot inhale chlorine or ammonia. These noxious gases automatically close the glottis, because they are irrespirable. Certainly a clever trick on the part of Nature, but unfortunately there are other gases that are even more poisonous, but which do not irritate the glottis and pass through it unnoticed.

The Respiratory Chambers. At the level of the heart the trachea ramifies until it has divided into about 25 million delicate branches, each $\frac{1}{50}$ in. in diameter. Each branch divides like a brush with its bristles into 12 to 20 terminal branches. Each terminal branch expands at its blind end to a respiratory chamber. The spherical respiratory chambers hang from the terminal branches like grapes on a stalk (d).

Berry-like Structures

To form an idea of these examine a cauliflower head and see how the central trunk branches out, and how small berry-like structures are attached to the ends of the most delicate branches. The lung has an analogous structure. To be sure, every little "cauliflower" piece in the lungs is no larger than the head of a pin, and altogether 400 million berries are attached to the ends of the branches of the windpipe as respiratory chambers.

Asthma and Emphysema. Like the blood vessels, the branches of the trachea, or bronchial tubes, have walls consisting of smooth muscle fibres that regulate their width. An asthmatic attack is a spasm of the bronchial musculature, so that it is

only with the greatest difficulty that an individual can breathe against the resistance of the spastically contracted muscle rings. Owing to the narrowness of the passageways, during the attack the air whistles audibly in passing through them. Conversely the bronchial tubes become dilated if the muscles are stretched too often by frequent exertions. Musicians who play certain wind instruments for many years, and people with chronic bronchial catarrhs are affected by this dilatation of the bronchial tubes, which can lead to a barrel-shaped distension of the thorax known in medicine as emphysema.

The Pleura. The lung is covered by a membrane known as the pleura, which bears the same relation to it as the pericardium does to the heart [Fig. 117]. The pleura of each lung forms a closed sac surrounding a cavity which is kept moist so as to lessen friction between the surfaces during respiration. The pleural sac is airtight and contains no air, thus helping to keep the lungs distended. In breathing, the diaphragm is drawn downwards and the ribs laterally, thus expanding the thoracic cavity and distending the lungs like

FIG. 160. *The flame of life. The rate at which oxygen is burned in the body depends upon the degree of muscular activity. When the body is recumbent and at rest, the vital processes are slowed down, and the organism requires only about 480 cubic inches of air per minute. Increase of activity entails acceleration of the vital processes and a proportionate increase in air consumption—even to as much as 3,000 cubic inches per minute.*

the bellows of an accordion. The respiratory chambers expand to three times their resting size, the air in them becomes rarefied, and owing to the pressure of the atmosphere the outer air enters the trachea and its branches. When the diaphragm relaxes and moves upward, the chest cavity diminishes, the thoracic walls press on the lungs, and we exhale.

The Gaseous Exchange. The large blood vessels that carry blood containing carbon dioxide from the heart to the lungs ramify together with the bronchial tubes, breaking up into millions of branches. The 400 million terminal branches of the bronchial tree are accompanied by an equal number of capillaries that surround the respiratory chambers with vascular networks resembling the wickerwork baskets around the carboys in which chemical companies ship their products [Fig. 159 (e)]. But blood does not leave the vessels. The gaseous exchange takes place through the thin walls of the capillary and the respiratory chamber according to the law of gas-pressure. The excess carbon dioxide (CO_2) passes from the capillary to the respiratory chamber, while the oxygen (O_2) travels in the opposite direction. It takes one second for a red blood cell to pass around a respiratory chamber. During this second the blood gives up its carbon dioxide to the air of the respiratory chamber, while the blood cell withdraws the oxygen from the respiratory air and passes on towards the heart with it.

The general mechanism of respiration and gaseous interchange are represented in Fig. 162 in the form of a "factory" where all the operations are co-ordinated. Air (1) flows through the nose (2), pharynx (3) and trachea (4) into the lungs (5). Here, oxygen from the air passes into the blood (6). Carbon dioxide leaves the blood (7), rises through the trachea (8) into the mouth (9),

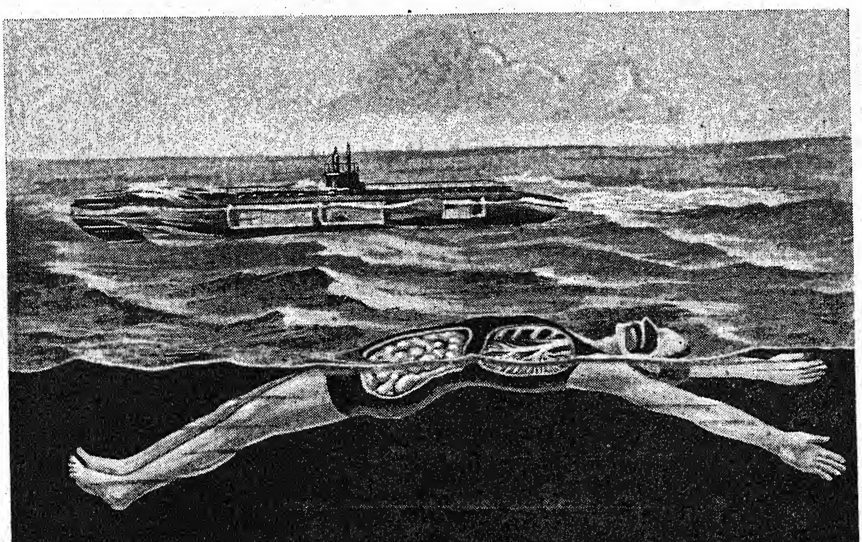


FIG. 161. *The human body does not sink in water, if it remains quietly relaxed. The head, thorax and abdomen all contain gases which make the body buoyant and keep it afloat.*

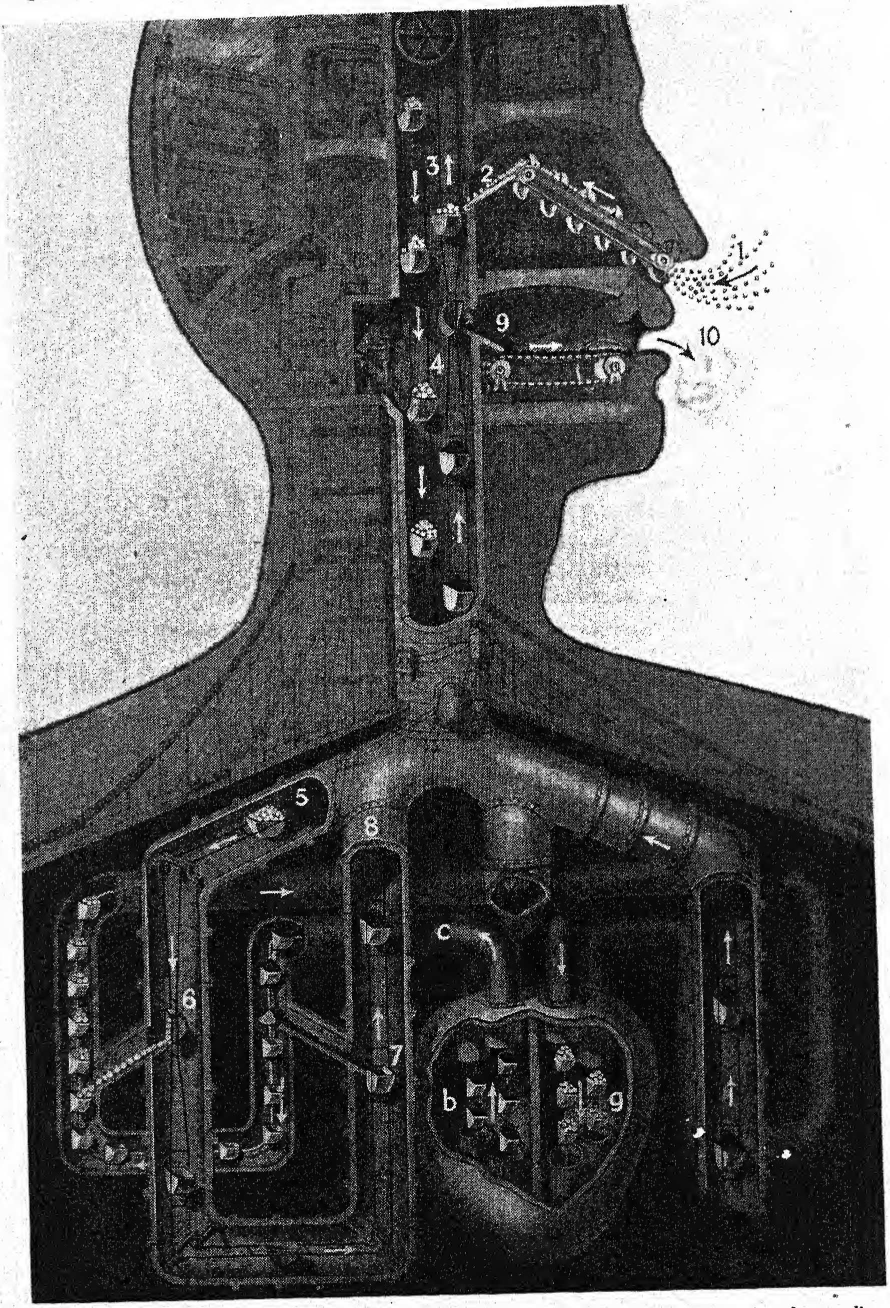


FIG. 162. *The interchange of gases in the "factory" of the lungs. The descending arrows show the path of oxygen molecules of the inhaled air; ascending arrows indicate molecules of carbon dioxide. For full explanation, see Pages 223-225.*

and is exhaled into the air (10).

At (g) and (b) are seen the chambers of the heart, containing oxygenated and carbon dioxide-laden blood respectively; (c) is the pulmonary artery. The regulators and switchboards represent the respiratory centre in the brain which controls the whole mechanism of breathing, by means of nervous impulses.

Breathing Capacity

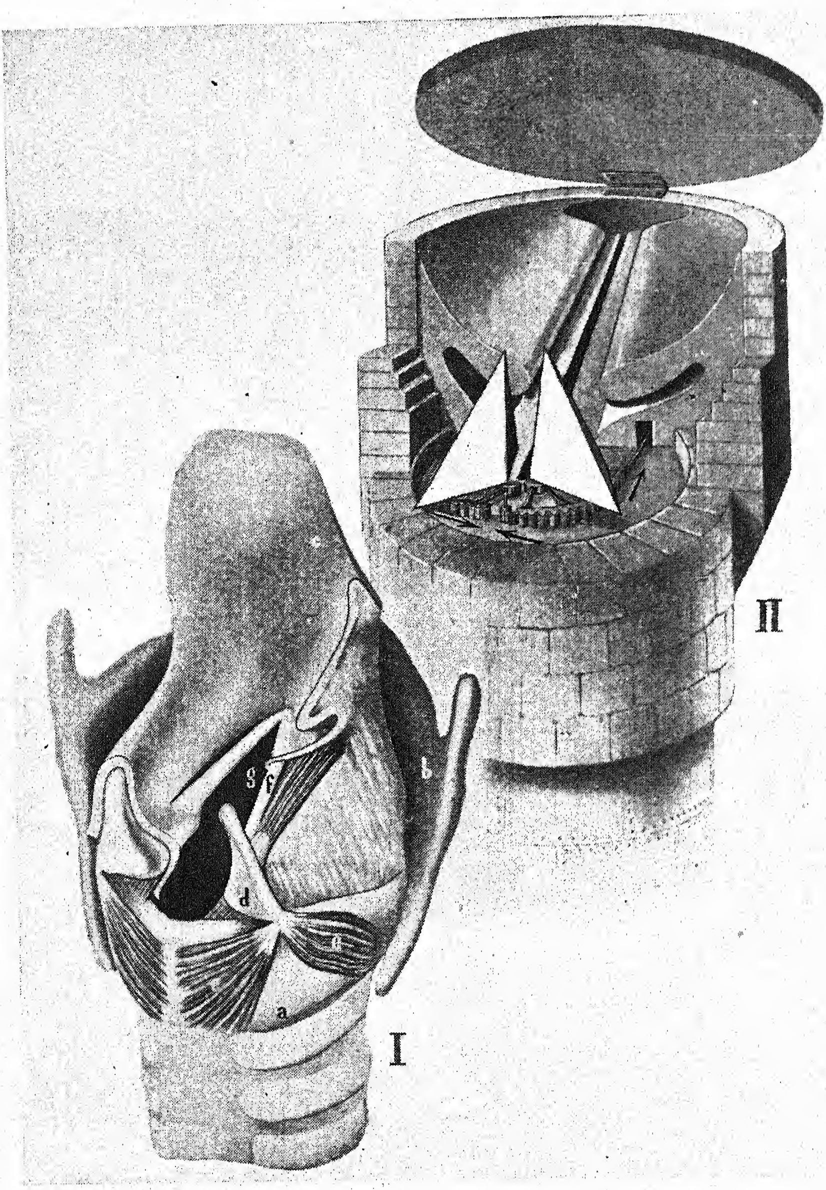
When moderately filled, the lungs contain 180 cubic inches of air. As 30 cubic inches of air are inhaled with each respiration, one sixth of the air is always being changed, guaranteeing a slow, even gaseous exchange without any considerable pressure variations in the terminal chambers. A person when recumbent uses about 480 cubic inches of air per minute, when seated 960 cubic inches, while walking 1,440 cubic inches, and in running 3,000 cubic inches per minute [Fig. 160]. In the course of a day an individual breathes about 375 cubic feet of air. As a result of athletic training the respiratory capacity of the lungs can be considerably increased. Oarsmen achieve the greatest respiratory capacities.

Man Does not Sink in Water! The specific gravity of the body is almost the same as that of water. The massive parts, the arms and legs, are heavier; the trunk with the gas-filled intestines and the air-containing lungs, and also the head with the air-filled nasal cavity and its accessory sinuses, are lighter. If a person lies quietly on the water, the arms, legs, and head sink downward; the abdomen, chest, and face remain above water [Fig. 161]. The head usually sinks so far that the mouth, nose, and eyes just remain above water, while the ears are covered by it. A person who is not afraid, but slides quietly into the water on his back, breathes easily and deeply so that his lungs will be well filled with air, and does not disturb this floating position, will not sink and can remain for several minutes in this "dead man's float."

The Respiratory Centre. In the medulla oblongata of the brain is a nerve centre, whose cells send a constant stream of nervous impulses to the diaphragm and the intercostal muscles stimulating them to contract. If the blood lacks oxygen the current becomes stronger and we must breathe more rapidly and deeply. This is called the respiratory centre.

Respiratory Control

We may imagine that we breathe involuntarily, or that our thorax breathes. As a matter of fact, we can actually accelerate or slow down our respiration to some degree by an effort of the will. By this means, trained divers can remain under water as long as four and a half minutes. The actual exchange of gases in the lungs is, however, outside our control, and is regulated by the respiratory centre in the brain, which functions automatically, without our conscious participation.



A MASTER MUSICAL INSTRUMENT

FIG. 163. *Man's principal vocal organ—the larynx (I). The cricoid cartilage (a) forms the base of the larynx; (b) is the thyroid cartilage and (c) the epiglottis, which forms the "roof." The right arytenoid cartilage (d) and its fellow are rotated upon their bases by delicate muscles (e), tensing the vocal cords (f) and so varying the width of the glottis (g). The technical model (II) shows the mechanism of rotation of the two arytenoid cartilages and the opening and closing of the epiglottis.*

CHAPTER XVIII

The Vocal Apparatus

THE LARYNX. THE VOCAL CORDS. CHANGE OF VOICE. THE RESONATING SPACES. THE VOICE. SPEECH. THE LIPS. THE TONGUE.

THE larynx, which contains the vocal apparatus, is situated on top of the trachea like a chimney-pot on a chimney [Fig. 163]. It consists of a framework of cartilages, and can be felt by the fingers in the front of the neck. At the bottom is the ring-shaped cricoid cartilage upon which the structure rests like an egg on the edge of an egg-cup (a); in the centre is the broad, shield-shaped thyroid cartilage (b), which consists of two plates meeting at an angle in front, but separated at the back so as to leave a V-shaped space in which most of the other cartilages are situated; and above them is an overhanging cover, the epiglottis (c), which is lowered to cover the larynx during the act of swallowing so that the food bolus crosses the respiratory passage-way as over a drawbridge [Fig. 180].

Coughing

If there is a mishap at this bridge so that the bolus enters the windpipe instead of the gullet, it gives rise to violent respiratory movements intended to expel the foreign body from the windpipe. In other words, it brings on what we all know as a fit of coughing. Coughing is a defence mechanism of the respiratory apparatus against foreign bodies of all kinds—food, mucus, inflammatory products, dry air, irritating gases, and the like. The act of coughing consists in a deep inspiration followed by a quick, violent expiration. The glottis is first closed and then suddenly opened so that the air contained in the windpipe is violently expelled along with any foreign matter present.

The Vocal Cords. Within the framework of the larynx the two arytenoid cartilages are situated like Egyptian pyramids on the upper edge of the posterior portion of the cricoid ring (d).

Precision Mechanism

The bottom part of each of the arytenoid cartilages is triangular and forms a rotating joint with the cricoid, within which it can be moved back and forth to some degree, by means of very delicate muscles. Two bands of elastic tissue, the vocal cords (f), pass across the respiratory canal from the anterior edge of each arytenoid cartilage to the angle formed by the two sides of the thyroid cartilage. The cords consist of highly elastic fibres; they may be said to be violin strings of the best quality. The space which remains open between them is the glottis (g). The arytenoid cartilages and the vocal cords are moved by sixteen muscles, which in their entirety form the most delicate muscle apparatus of the body, a true precision mechanism. They rotate the arytenoid cartilages, thus tensing or slackening the cords, and making it possible

for them to assume altogether about 170 positions. In order to produce a sound, the arytenoids are placed in such a position that the glottis opens at a certain angle, thus creating a degree of tension in the vocal cords just as a violinist does in tun-

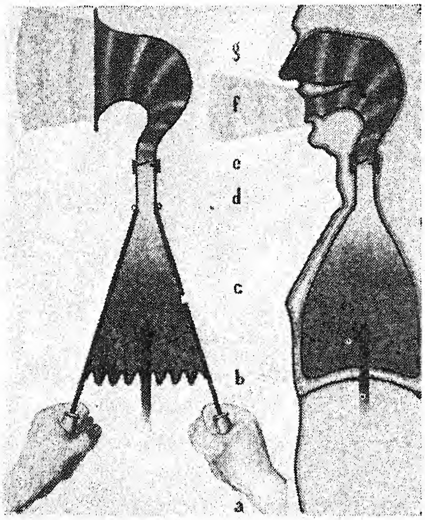


FIG. 164. *The human vocal apparatus is analogous to a double-reed wind instrument. Abdominal pressure (a) pushes the diaphragm (b) upward against the air-filled thoracic cavity (c). Thence a column of air is forced through the trachea (d), in which are situated the vocal cords (e); by their vibrations, these break up the air into sound waves (f). In the mouth and resonant sinuses (g) the sound waves are combined into musical tones.*

ing his strings. Now a precisely determined quantity of air is blown upward through the glottis at a certain velocity by means of precise movements of the diaphragm and the intercostal muscles. Under the impact of this stream of air the vocal cords begin to vibrate, causing the column of air within the respiratory passages to vibrate. We hear the vibration of the column of air as a sound [Fig. 164]. If the vocal cords are moderately tensed, so that they vibrate about 80 times per second and the amplitude of the vibrations is large, long waves are produced which are heard as deep tones. If the cords are tightly tensed, they vibrate rapidly, 1,000 times per second, giving rise to short waves and high tones.

Change of Voice. A child has a small larynx with short vocal cords. It produces short air waves and consequently the child has a high-pitched voice like a violin. At puberty the larynx begins to grow and the vocal cords become longer: in an adult female they are almost $\frac{1}{2}$ inch long; in an adult male $\frac{7}{10}$ inch. In consequence the voice changes, becoming deeper. In boys growth is so rapid and the difference in the size of the musical instrument in the throat is so great that they cannot get used to it and often lose control of the voice. This phenomenon is commonly called "the breaking of the voice." While the general pitch of the adult voice is dependent on the length attained by the vocal cords, each voice has a certain range which determines to which class it belongs. On this basis voices may be divided into six groups: bass, baritone, and tenor for men, contralto, mezzo-soprano, and soprano for women. Female voices are pitched about an octave higher than male voices. A child may be compared to a violin, a woman to a viola or a cello, and a man to a double-bass.

Regarded as a musical instrument, the larynx is a combination of violin and wind instrument which is nonexistent among man-made instruments. It is a wind instrument because it is set in motion by an expiratory current of air. However,

the tongues that vibrate under the impact of the blast of air are cords like violin strings.

The Resonating Spaces. If a tone is produced on a trumpet and another of equal pitch on a violin, the pitch of the two tones is the same but their quality or timbre is very different. The arrangement of the air emanating from each instrument is not a simple series of waves, such as arises behind a ship's propeller, but rather a combination of waves such as is produced when the waves from the ship's bow and propeller meet far away from the ship, or like the ripples produced by a wind on the surface of a body of water. The tone produced by a violin is not a simple wave structure created by vibrating strings but a tissue of tones arising from the vibrations of the entire instrument. By means of the sympathetic vibrations of an environment shaped according to definite laws and known as a resonating space—for example, the wooden sounding board of the violin and the metal structure of the trumpet — over-tones are produced which transform the simple tone of the vibrating strings or tongues into a complex tissue of tones. In contrast to pitch this is called quality or timbre.

The vocal apparatus is a musical instrument with walls consisting of bones, muscles, and moist mucous membranes, and equipped with numerous resonating membranes, walls, and air spaces [Fig. 165]. Above each vocal cord is a depression bounded by a prominent edge known as the false vocal cord, which forms the first and closest resonating space of the vocal apparatus. The other resonating spaces are the windpipe (6), the lungs (7), and the thorax beneath the larynx, and above it the pharynx (5), the oral (4) and the nasal cavities (2), as well as the accessory nasal sinuses (1). If the thorax resonates, the voice is produced in the chest register; if the resonating spaces of the head are used, the voice changes to the head register. The

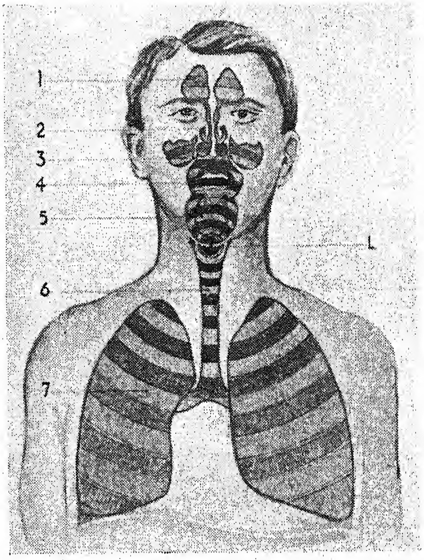


FIG. 165. *The resonating spaces of the human vocal apparatus: (1) the frontal sinuses, (2) the nasal cavities, (3) the maxillary sinuses, (4) the oral cavity, (5) the pharynx, (6) the trachea, (7) the lungs. At (L) is the larynx.*

range and the quality of a voice depend on the form and size of the resonating spaces. Persons with beautiful voices will be found to have resonating spaces so shaped as to produce sounds which musical theory and the principles of instrument-making confirm to be musically perfect.

No musical instrument can be compared to the vocal mechanism as regards the fineness of its strings, the number and development of its resonating spaces, and the wide

possibilities which it possesses for changes of register and consequently for richness of tonal quality. In opera an entire orchestra plays, but above it sings one human being with a small larynx, and the human voice triumphs over all artificial instruments.

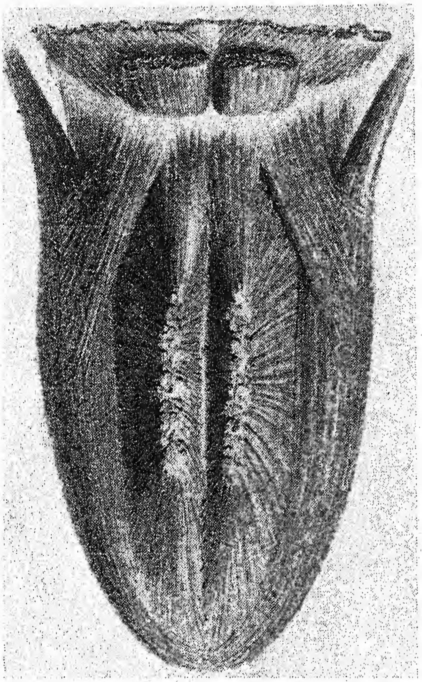


FIG. 166. *The arrangement of the muscle fibres of the tongue, as seen from below.*

The Voice. The larynx is not the organ of speech, as is generally stated, but the instrument of voice-production. A singer does not sing exclusively with the larynx, but with the entire vocal apparatus from the diaphragm below to the frontal sinus.

Sing the vowel " a," as in the word " far," observing at the same time what happens to the body. The abdominal wall is kept in a certain state of tension, and the diaphragm is slowly pressed upward towards the thoracic cavity like the piston of a syringe, thus pushing air up through the windpipe and out of the mouth. On its way the column of air passes through the larynx, where it is caused to vibrate by the vibrating vocal cords. The pitch of the tone changes in accordance with the degree of tension of the vocal cords. If a hand is placed against the chest wall during speech the entire thorax can be felt vibrating as a resonator, just as a violin does when its strings vibrate. On touching the head one feels that the skull, jaw, cheeks, and forehead are also vibrating. If the mouth is closed, there is no longer an " a " sound, but only a humming.

The vowel " a " is produced when the oral cavity is made to assume a particular shape: tongue flat on the floor of the mouth and lips relaxed to form a wide, circular opening [Fig. 167 (*Right*)]. By varying the shape of the opening, the " a " vowel sound can be transformed at will into the vowel sounds " u," " i," and " o."

The vibrating vocal cords divide the ascending air column which passes between them into waves, thus determining the frequency—that is, the pitch and the purity of the tone. The quality of the tone, however, is determined by the resonating spaces.

On the other hand, consonants require the entire vocal apparatus: abdomen, chest, larynx, mouth, nose and accessory sinuses, diaphragm, intercostal muscles, tongue, palate, lips, and teeth. Each of us is a musical virtuoso, because we play masterfully on one of the most complex and difficult musical instruments that we know, the human vocal apparatus. We can play it so well only because we learned this art when we were most adaptable and since

then we have practised it repeatedly.

Speech. Spoken words consist of vowels and consonants. Say *u, o, a, e, i,* aloud, and observe the changes in the mouth cavity, where they take their origin [Fig. 167]. Vowels are musical tones possessing a certain timbre. Now pronounce a number of consonants: *b, d, f, g, k, l,* and the nature of consonants will be recognized without any difficulty. In contrast to vowels, consonants are sounds produced by checking the expiratory blast of air on its way through the pharynx and mouth. Thus when we pronounce *b,* the lips are pressed together and the expiratory current of air is interrupted. Then the interruption is suddenly removed by opening the lips, giving rise to the explosive *b* sound. The sibilant *s* is produced by forcing the air through a narrow passage created by bringing the teeth near the palate. *R* is formed by placing the tip of the tongue in the path of the expiratory air so that it is set into vibration.

The Lips. The entire musculature from the abdomen to the nose participates in the production of speech sounds. Most important, however, for the special formation of spoken sounds are the muscles of the mouth, the palate, lips, and tongue. The lips consist of interlaced muscle fibres covered by skin on the exterior, and mucous membrane on the interior, surfaces.

The Tongue. The tongue is exceptional in that it is the only muscle which is attached only at one end. On this account it is endowed with a capacity for mobility unattained by any other muscle. The tongue is a composite organ. In its interior it is a muscle, on its surface it is an apparatus with which food is broken up into smaller particles. The surface of the tongue is a system of small graters, rolling - pins, kneading boards, brushes, rakes, and points that bore into the food particles and act on them in a variety of ways [Fig. 176]. Thirdly, the tongue is one of

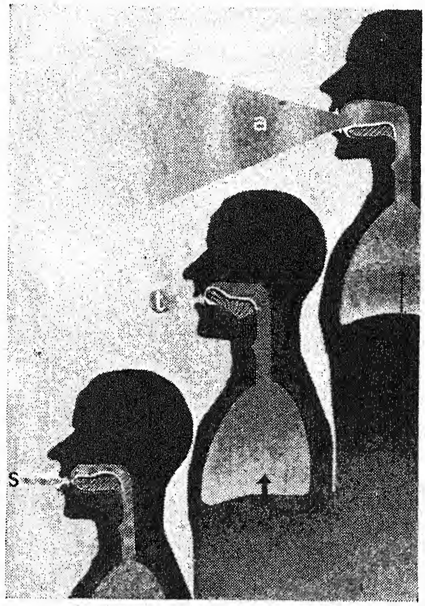
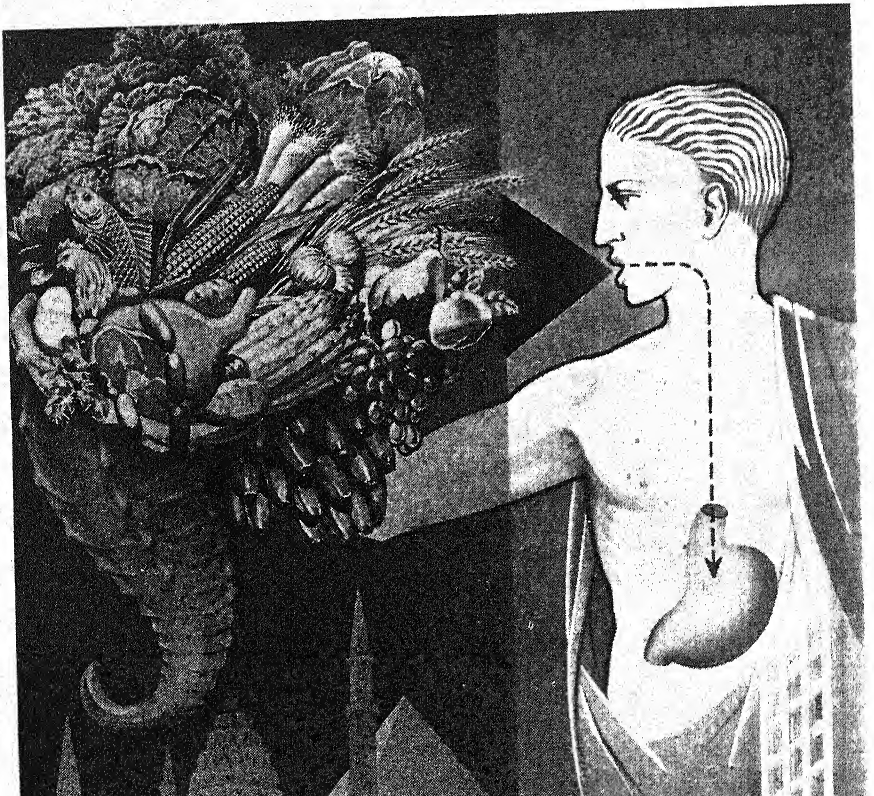


FIG. 167. *Vowels ("a") are tones that are sung. Consonants ("t," "s") are disturbed tonal formations. When a number of vowels and consonants are pronounced in succession, the variations in the shape of the mouth can easily be observed.*

the most delicate apparatuses of the sense of touch, and fourthly, it bears the taste buds, so that it belongs to the sense organs as well as to the muscles. In producing individual sounds it assumes the most varied forms and positions. Now pronounce the letters of the alphabet aloud and slowly once more, observing the tongue while doing so. In this way one arrives at a true conception of the functions and capacities of this highly versatile and adaptable organ.



ARCHITECTURE OF DIGESTION

FIG. 168. *Man, who feeds on plants and animals, faces the same problem as an architect who must build a single edifice with the diverse materials from several buildings of different styles. For this to be done, the buildings must first be pulled to pieces.*

VI : DIGESTION

CHAPTER XIX

The Problem of Nutrition

WHAT IS "FOOD"? THE TWO TASKS OF THE DIGESTIVE APPARATUS. CARBOHYDRATES. FATS. PROTEIN. THE GLANDS. FERMENTS.

THE basic substances from which plants build up their products are simple compounds: water, carbon dioxide, ammonia. The molecules of these substances are small, containing three to six atoms. From these simpler compounds the plant builds more complex ones in which dozens and hundreds of atoms are united. In order to combine the small and free atomic groups a certain amount of energy must be expended, just as force must be used to yoke two wild horses together in a team. This expended energy, which is now bound in the molecule, is called the potential energy. Imagine that several spiral springs have to be forced into a case. Energy is needed for this purpose. If the case is opened later, the springs fly out, thus using up the energy which had been expended to force them together and which, in consequence, was stored up as potential energy.

The spiral springs represent the free simpler molecules; the case in which several dozen springs are pushed together is the complex molecule of sugar, starch, or oil. If this molecule is broken down, the energy, which had originally been required to force the springs into the case, is liberated. A plant takes the energy for this work from the sun's rays. The energy contained in the complex molecules of a plant's fruits, their nutritive value, is solar energy. A fruit is a storage battery charged with the electrical energy of sunlight. A person who eats potatoes introduces sunlight batteries into his body and moves about like a motor driven by their energy. In order to make available the potential energy contained in the storage batteries of the large food molecules, man's body has developed a special apparatus, the digestive apparatus [Fig. 169].

The Two Tasks of the Digestive Apparatus. The digestive apparatus has two tasks. Its first task is to break down the large food molecules so that they can be transported through the body. Large molecules cannot pass through the cell and tissue walls. A starch molecule cannot wander from one cell into another. "*Corpora non agunt nisi soluta*" is one of the oldest principles of physiology—"Substances act only when dissolved." Starch must be broken down to sugar, oil to soaps, and protein to amino acids before they can pass through the cell walls. The second task of the digestive

apparatus is to transform the foreign molecules of the food into specifically human molecules. Man ingests molecules of all kinds: cow's milk, chicken meat, wheat starch, coffee, potato starch, and sardine oil. A human being can swallow an oyster, but he cannot replace any part of the body with oyster protein. The human body consists of molecules of human protein, and for the most part the molecules are present in special arrangements. Consequently, only molecules of this special kind can be used to replace or repair any injured parts, just as only spare automobile parts can be used for automobile repairs.

The human body, which receives varying proportions of plant and animal substances as food, faces the same problem as an architect who is shown an old section of a city and told to transform it into a modern urban district. In such a case there is only one method of attack: to tear down and build up anew. This is what man does: he must break down the molecules of butter, flour, fish, and fruits into their elements, and build up human proteins, fats, and starches from them [Fig. 168].

Chemistry of an Apple

Carbohydrates. The manufacturer of foodstuffs is the plant. It takes carbon dioxide (CO_2) from the air, and water (H_2O) from the soil, and builds up complex compounds by means of the energy furnished by the sun's rays. The simplest compounds formed from CO_2 and H_2O are formaldehyde (CH_2O) and simpler acids related to formaldehyde. Acids appear first in the process of synthesizing food substances. Because of this fact unripe fruit is sour. A boy who steals an apple in midsummer makes a "sour" face [Fig. 170 (a)].

But the plant is industrious. It repeats the process, combining 2, 4, 6 molecules of formaldehyde, giving rise to sugar ($C_6H_{12}O_6$). In autumn the acids in the apple have been transformed into grape sugar, and the apple is sweet (b). Now man reaps the crop, but the plant continues to manufacture. It combines two molecules of grape sugar to form malt sugar; malt sugar molecules combine to form dextrin; and by uniting dextrin molecules the plant makes starch. In winter the apples loses its sugar and becomes mealy (c). Then the plant combines starch molecules to form cellulose. In late winter the apple is no longer sour, sweet, or mealy, but quite woody and tasteless (d).

Sugar, Starch, Cellulose

The class of substances which the plant builds from carbon dioxide and water is known as carbohydrates. Sugar, starch, and cellulose are the three most important forms in which carbohydrates are contained in human food. *Corpora non agunt nisi soluta* — substances do not act and wander unless dissolved. Take a glass of water and first throw some cellulose into it—for example, some cotton or cork, or a piece of wood. They do not dissolve and are therefore unable to travel in the human body.

Now put a lump of common starch or a teaspoonful of flour into the water. Neither of them dissolves, so that they too are unable to wander through the body. Now throw a piece of sugar into the water; it dissolves. Sugar is thus able to wander through the body. This simple experiment demonstrates the essence of digestion. In order to be able to travel

around in the body, carbohydrates must be transformed into sugar. In order for the blood vessels to be able to absorb them, starch and cellulose must be broken down again by the body to sugar, just as the plant builds them up stage by stage from sugar.

Fats. Not all simple acids that form in plants are turned into carbohydrates. Some of them are combined to form more complex acids. Figure 205 represents schematically

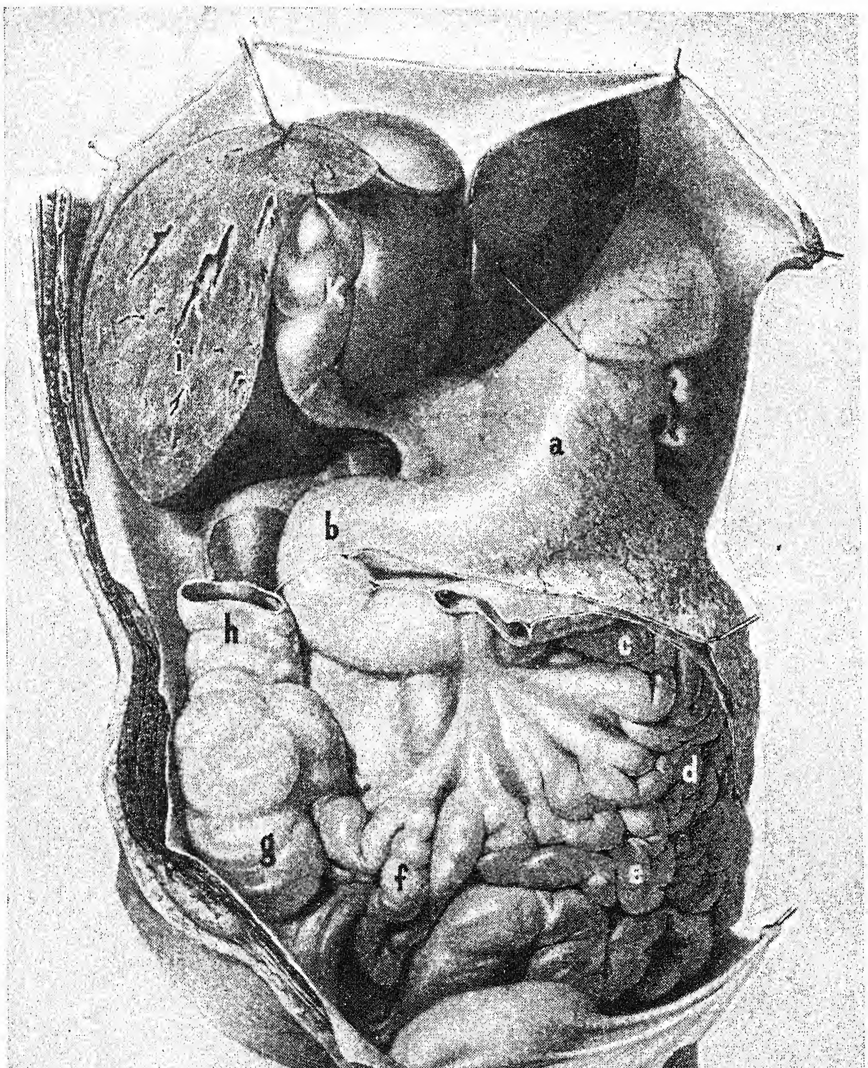


FIG. 169. *The digestive apparatus, consisting of: (a) stomach; (b) duodenum; (c, d, e, f) small intestine; (g) cæcum; (h) large intestine; (i) liver; (k) gall-bladder. These organs form the mechanism for rebuilding food molecules into "human" molecules.*

the chemical series of plant acids. As the lowest row shows, an organic acid has the basic formula CH_3COOH. Higher acids are produced, as one recognizes from the upper rows, by the addition of the atomic group CH_2. By repeated addition of CH_2, plants form complex acids from such simple compounds as formic acid or does not disappear when it is poured into water. By thorough shaking, however, it can be divided into droplets that disperse through the water and render it cloudy. If a few drops of eau de Cologne, which contains the oils of certain scents, are allowed to trickle into water, it becomes cloudy. On examining this water

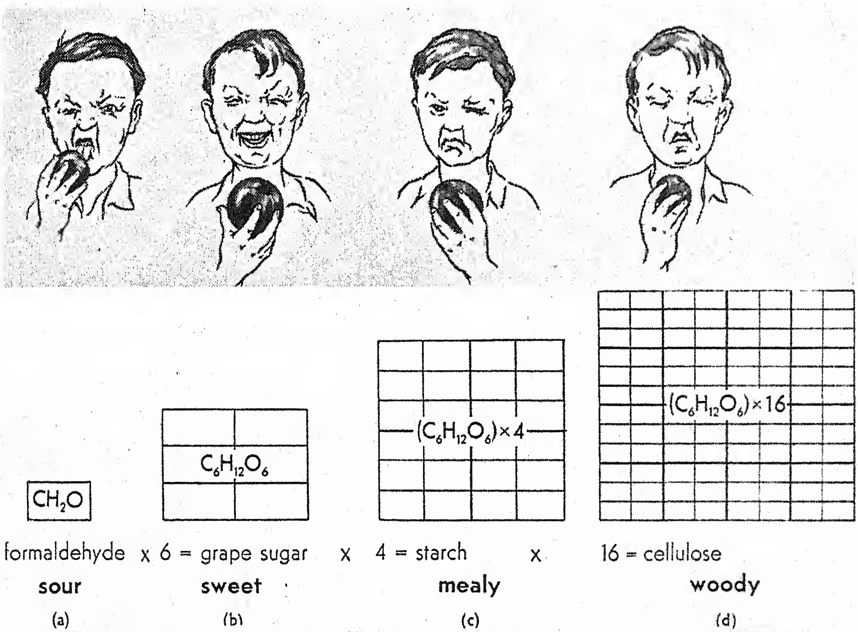


FIG. 170. *An apple in midsummer is acid and sour (a), but by autumn it has grown sweet (b). Later, it becomes mealy (c), and eventually tough and woody (d). These changes result from the building up from acid of sugar, starch and cellulose in turn.*

acetic acid. The highest of these compounds containing 12, 14, and 16 CH_2 groups are oleic, palmitic, and stearic acids. These acids are known as the fatty acids because they are the chief constituents of the second group of food substances, the fats. Fat is formed by the union of fatty acids and glycerin. Fluid fats are called oils. Fats are also directly insoluble, and are consequently unable to wander through the tissues. Oil with a magnifying glass, the oil droplets may be seen floating in it. A dispersion of insoluble fat in water is called an emulsion. Milk is an emulsion with which we are all acquainted. If the milk is centrifuged, the oil particles separate out and collect in the form of butter. Since fats do not dissolve, but form only finely dispersed mixtures or emulsions, they must likewise be split into their soluble constituents, glycerin and

the fatty acids, during the digestive process, before being used by the body.

Protein. The third group of food substances are the protein compounds. Protein differs from carbohydrates and fats in that it contains nitrogen. Protein consists of acids, which contain nitrogen in the form of the amino group NH_2, so that they are known as the amino acids. The amino acids are the structural elements of protein [Fig. 171 (a)]. Protein consists of chains of amino acids, combined in a most varied manner, thus forming molecular groups of increasing size. The first group formed are the peptones (b); by linking peptones together, albumoses (c) are produced; and by uniting albumoses, the various proteins, of which there are innumerable kinds, are created (d).

Think of the lace industry. Lace consists of threads woven by the basically simple method of tying knots. Yet there are thousands and thousands of lace designs, all made by the same basic method, but arranged very differently. The world of the protein compounds is a world of lace designs, woven from chains of amino acids. The combined amino-acid groups are likewise too large to pass through the membranes of the body. They must be split up into their amino acids. The travelling form of the proteins in the body is the amino acid.

The digestive apparatus is a mechanism by means of which the carbohydrates are split up into soluble sugars, the fats into fatty acids and glycerin, and the proteins into amino acids. Thus the large food molecules that are unable to wander through the body are broken down to pass through membranes. Take a hen's egg and let the egg white flow out on a plate; now put a piece of butter and a lump of sugar near it. Here one sees the classes of food substances: protein, fat, and carbohydrate.

The splitting up of the large food molecules into small travelling molecules takes place in steps as represented schematically in Figure 172. The large food molecules are attacked and broken down by special apparatuses in different sections of the digestive canal. As indicated by the sequence of the numbers, the most important stations are: (1) the mouth, (2) the stomach, (3) the liver, (4) the pancreas, (5) the small intestine. A certain phase of digestion takes place in each section until all the food molecules have been broken down to the component, wandering elements. The description of these

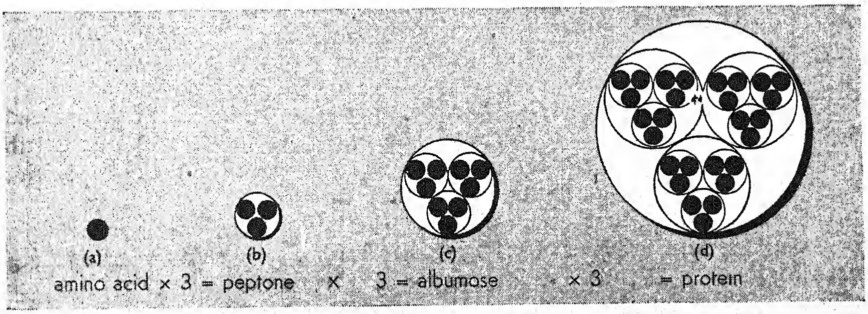


FIG. 171. *How protein is built up by combining groups of amino acids.*

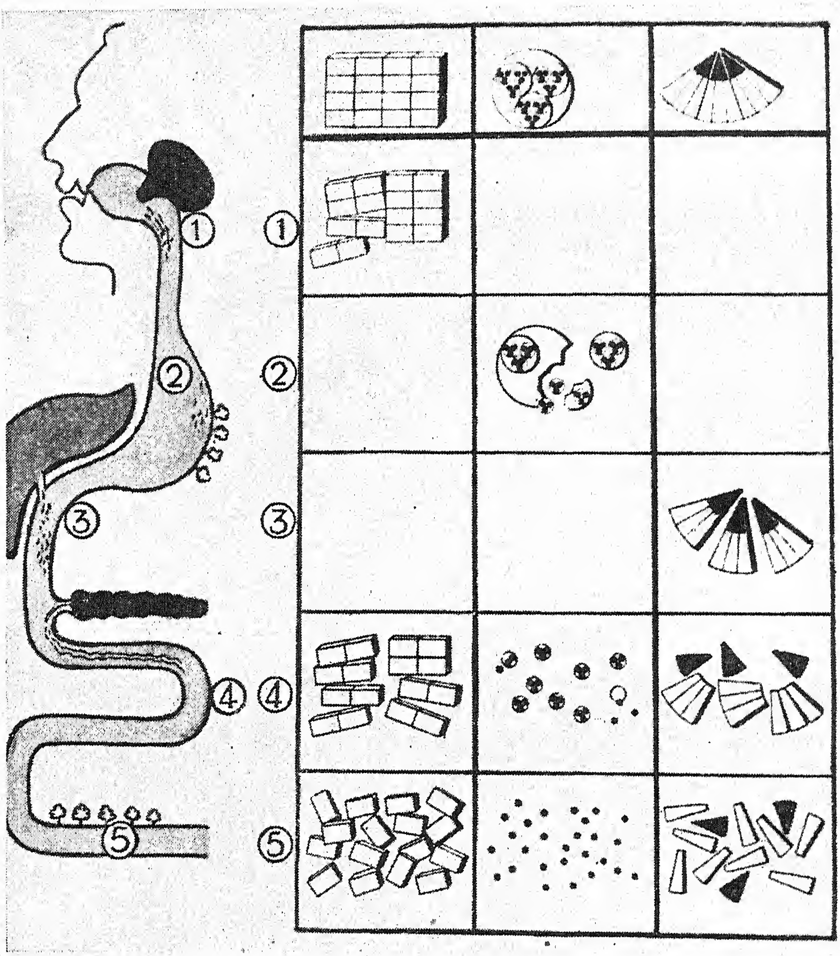


FIG. 172. *The large food molecules (top row) cannot pass through the cell walls, and must therefore be broken down. This process occurs in successive stages in the various organs of the digestive apparatus, as follows: (1) the digestion of starch in the mouth; (2) the digestion of protein in the stomach; (3) the emulsification of fat by the bile; (4) further digestion by the pancreas; (5) final digestion by intestine.*

successive phases is the content of the science of digestive physiology.

The Glands. The splitting up of the molecules in the digestive apparatus is carried out primarily by means of the secretions of special organs called glands. Glands are organs whose cells manufacture certain chemicals. All the glands of the body are basically alike and closely related, but they manufacture different substances. According to their position they are classified as follows:

1. Skin glands, that secrete their products on the skin—sweat, sebaceous, tear, and milk glands.

2. Digestive glands, which secrete into the intestinal canal [Fig. 172]—

the salivary (1), stomach (2), and intestinal glands (5), as well as the liver (3), and pancreas (4).

3. Endocrine glands, which deliver their products directly into the bloodstream—thyroid, adrenal, pituitary, pineal, and sex glands, and the island tissue of the pancreas.

4. Excretory glands, which regulate the exchange of waste materials between the blood and the outer world—the kidneys, sweat glands, and to a certain extent the lungs.

In Figures 173 and 174, the female breast, the milk gland of the human body, is represented as a typical example of a gland. In the embryo the milk gland develops, like all glands, from a depression of the tissue—in this case the skin of the chest—in the form of a microscopically fine tube called the milk duct. This tube ramifies beneath the skin, giving rise to an arboriform system of ducts, the milk canaliculi, numbering several hundred thousand. At their blind ends the tubes are dilated to berry-shaped tiny "grapes."

The isolated gland "grape" in Figure 173 (e) is typical of all the glands of the human body. It consists of a wall of cells with granular protoplasm surrounding a cavity. These cells manufacture the product of the gland. Figure 174 represents a greatly magnified gland berry with all the important elements concerned in its construction. At (a) is a blood vessel which brings the raw materials necessary for the production of milk to the gland cells. These raw materials—protein, fat, sugar, calcium, phosphorus, iron, arsenic, vitamins, hormones, etc.—are represented pictorially by six different symbols. The blood vessel carries the substances to the cell (b). In its back wall the cell

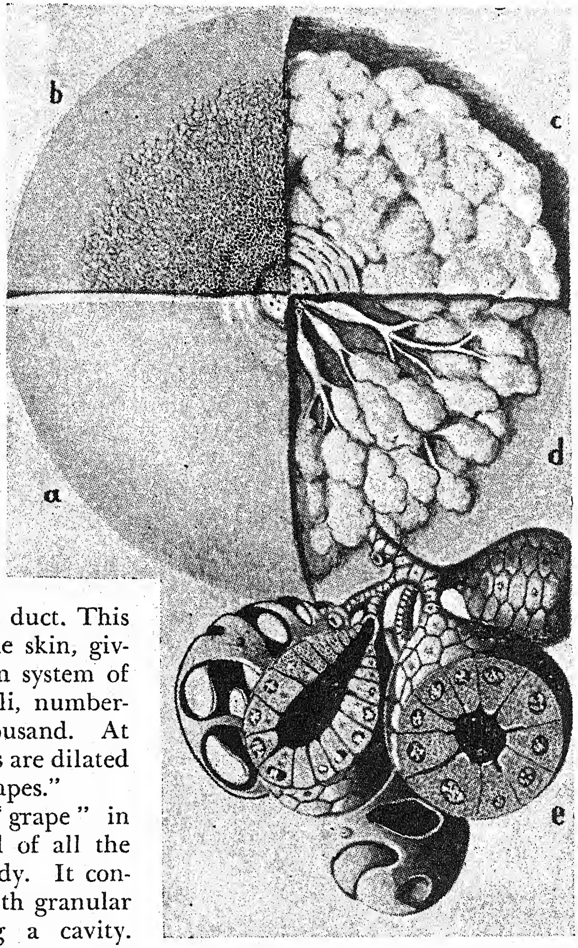


FIG. 173. *The structure of a gland, exemplified by the female breast, or mammary gland. The illustration shows (a) the skin; (b) the lymph-vessels beneath the skin; (c) fat surrounding the gland tissue; (d) the lobules of gland tissue; (e) terminal chambers, or alveoli*

has "sieve holes." Through these spaces the materials enter the interior of the cell, where they are subjected to a special vital process by the protoplasm. The protoplasm smashes the imported food fragments and builds a specific product from them, depending on the type of cell in which the process takes place.

Alchemy of a Gland

The cells of the human milk gland make human milk, which differs from all other kinds of milk. The transformation of the imported substances may be traced in the picture. Within the cell the symbols fall apart into fragments, and from these the protoplasm composes new mosaic patterns. Then they flow out through the duct of the gland (3) as human milk.

As we see, the gland is lavishly equipped with numerous accessory devices. On their inner surface the cells are held together by a mesh framework (c) so that they will not shift their position. Their back wall is covered by a fine membrane, like a layer of cellophane, known as the glassy membrane (d). A thick layer of muscle fibres (e) surrounds the "berry" in order to squeeze it out when it is filled with milk. Nerve cables (f) bring the orders from the brain to the cells. Numerous lymph-vessels (g) carry away the waste products. And this entire complex organization is compressed together within a space which is one quarter as large as the dot over this "i." In our body we carry about perhaps 60 million or even twice as many gland "berries." If we were to take all the industries on the earth, reduce them to microscopic dimensions, and place them within the framework of a human body, they would probably not suffice to compete with the organization of the human body.

Ferments. In order to obtain a tangible idea of the nature of molecular structure, imagine that molecules are plates united by means of screws [Fig. 175]. The smallest plate is the grape-sugar molecule (a). Two grape-sugar molecules screwed together form a molecule of malt-sugar (b). Two malt-sugar molecules unite to form a molecule of dextrin (c); two dextrin molecules form a glycogen molecule (d); and two glycogen molecules build a molecule of starch (e). Glycogen is the starch found in the animal body, in the liver, muscles, and gland cells. The plant starch of flour, potatoes, and beans is chemically a somewhat higher and firmer form than the animal starch glycogen; essentially, however, they are closely related to one another.

In order to separate the relatively large starch molecule into its very small plates, the grape-sugar molecules, the uniting screws must be loosened. To be able to do this a spanner is necessary, and a separate one for each different kind of screw.

Everlasting Keys

The spanners are provided by the glands, and these key substances are called ferments or enzymes. A key may be small even for opening a large money-chest; this is also true of the ferments. Only a trace of a ferment is needed to split up large quantities of complex substances. A key does not wear out, and can be used for years to open money-boxes. Ferments likewise manifest the same property. After they have performed their function of splitting the food substances they are present exactly as before. Thus a ferment is a substance which

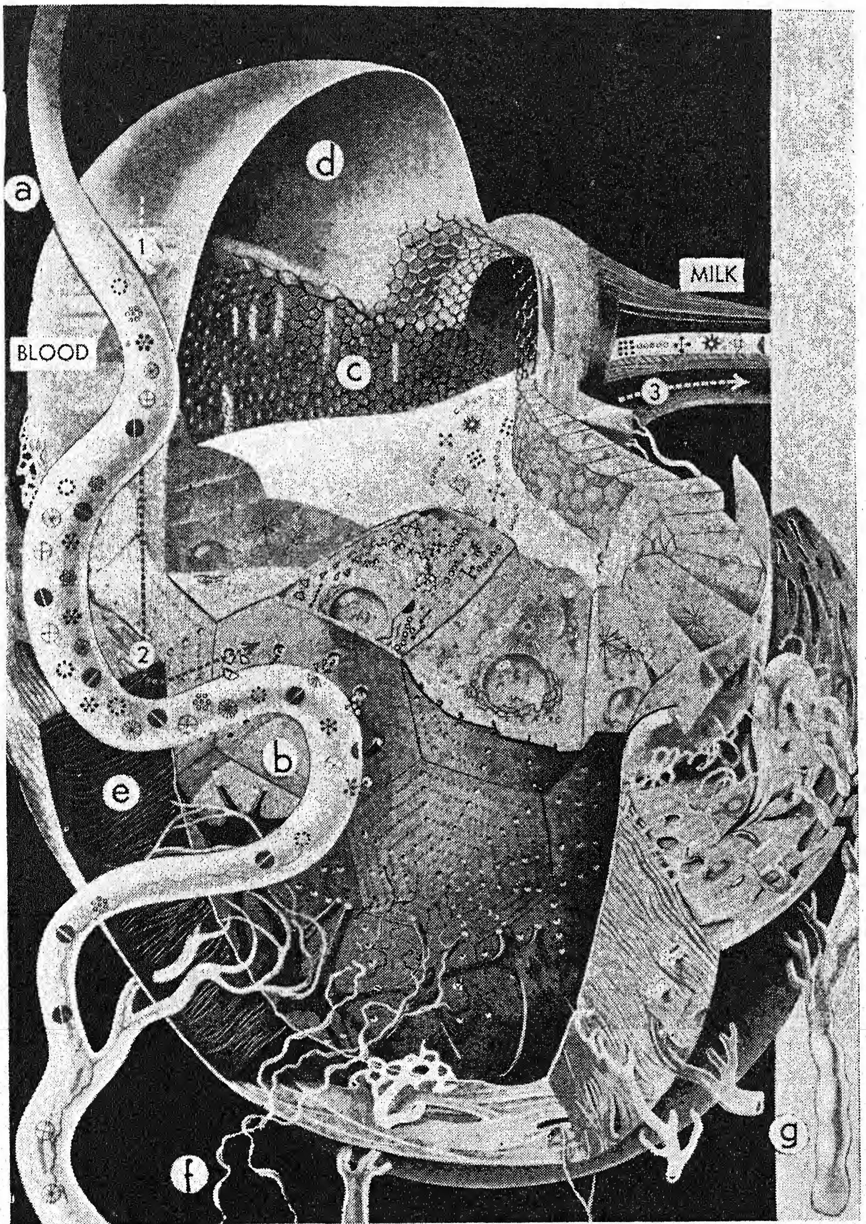


FIG. 174. *One of the millions of terminal alveoli of the female breast during the secretion of milk.* [*Compare Fig. 173 (e)*]. *The blood brings to the gland the basic substances (1–2), represented by six symbols; the glandular cells (Centre) make human milk from them (3). The picture also shows (a) blood vessel; (b) gland cell; (c) sieve membrane; (d) glassy membrane; (e) muscle layer; (f) nerves; (g) lymph-vessels.*

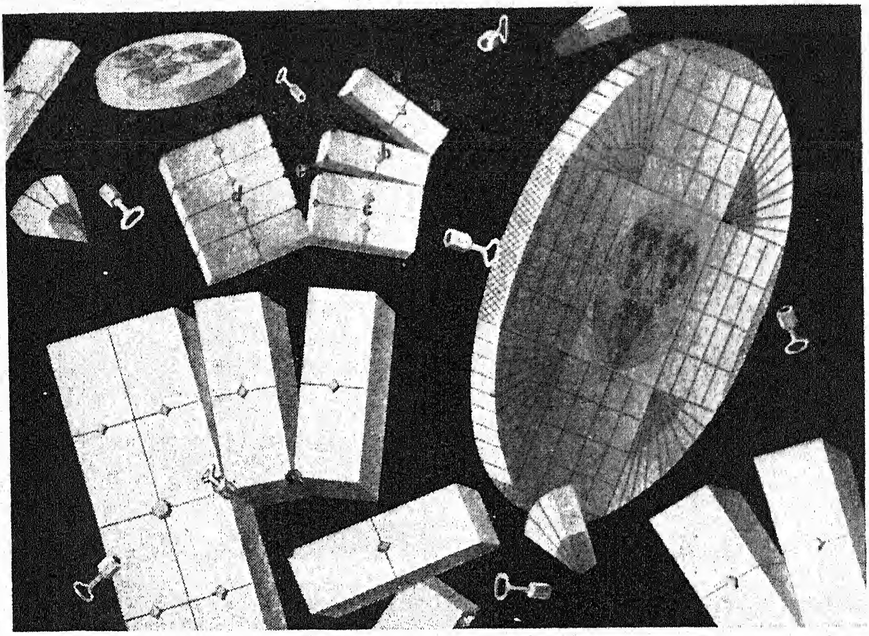


FIG. 175. *Digestion in the mouth. Of all foodstuffs, only starch is changed chemically in the mouth. Ptyalin, the salivary ferment, separates the large starch molecules (e) into their components, somewhat as a key or spanner undoes screws and bolts. The starch is broken progressively into glycogen (d), dextrin (c), and malt-sugar (b). The further reduction to grape sugar (a) does not take place in the mouth, but in the small intestine (Chapter XXIII).* *(See also Figs. 185, 194 and 202.)*

serves to split complex compounds into their component elements (or conversely to build them up from these simpler components). It need only be present in very minimal quantities to be effective, and is not used up in the course of its work. Yeast juice contains a ferment. A crumb of yeast suffices to ferment a whole bowl of dough. The juice of the kefir fungus also contains a ferment, and a crumb of kefir can be used daily for many years to turn several quarts of milk into "kefir" (a Caucasian effervescent drink), just as a clock can be wound up daily for many years with a small key. Not only are ferments the key substances for the splitting of the large food molecules, but they also play a major part in combining these fragments to form the molecules of the human body. Their significance for the body is so great that physiologists have gone so far as to characterize life itself as a succession of ferment reactions.

CHAPTER XX

The Mouth

DIGESTION IN THE MOUTH. CHEWING. THE SALIVARY GLANDS. THE REGULATION OF SALIVARY SECRETION. SALIVATION AND NUTRITION. DENTAL TARTAR. THE SALIVARY FERMENT. DEGLUTITION. THE UVULA. THE EPIGLOTTIS. THE GULLET (ŒSOPHAGUS). ARTISTS IN SWALLOWING. HUMAN RUMINANTS.

THE breaking down of the food takes place in stages. The digestive canal is equipped with glands, arranged in series behind one another, which "loosen the screws" between the molecules by means of their key substances, the ferments. The first section of the digestive canal is the mouth. Here the food is subjected to five processes. It is tested by the sense organs, cut up into smaller pieces by the teeth, treated chemically by the saliva, formed into a bolus by the tongue, and swallowed by means of the muscles of the œsophagus.

Three-fold Scrutiny

Three sense organs—eye, nose, and tongue—participate in testing food. The eye is a long-distance apparatus. It examines an object at a distance and determines whether or not it belongs to the category of food. After the eye has recognized at a distance that the substance is food, the nose tests it for edibility. It determines whether meat is fresh or spoiled. After this second examination the food is placed in the mouth, and now the tongue determines its taste. Not only are the impressions received by the sense organs decisive for the acceptance or rejection of food, but they also act internally as "starters"; they crank up the digestive organs by way of the nervous system.

Chewing. Take a slice of bread and bite off a piece as you usually do. Then, however, do what we generally do not do; observe carefully what happens [Fig. 176]. With the incisors we bite off a small piece corresponding in its dimensions to the size of the mouth. Then we push the fragment between the teeth, but not backwards. Instead, it is held firmly by the canines and "sawed" into small pieces by the premolars. After being completely "sawed" into small pieces, the bread is pushed between the large millstones of the molars, where the pieces are slowly but powerfully ground.

Tools of the Tongue

After being cut and ground into bits, the food is pushed on to the tongue where it is treated by means of the elastic kneading apparatuses of the tongue. The tongue is a chopping and baking board, but not like one used in a kitchen where the implements used on it are kept separately. The baking and chopping implements of the tongue are an integral part of this organ and function

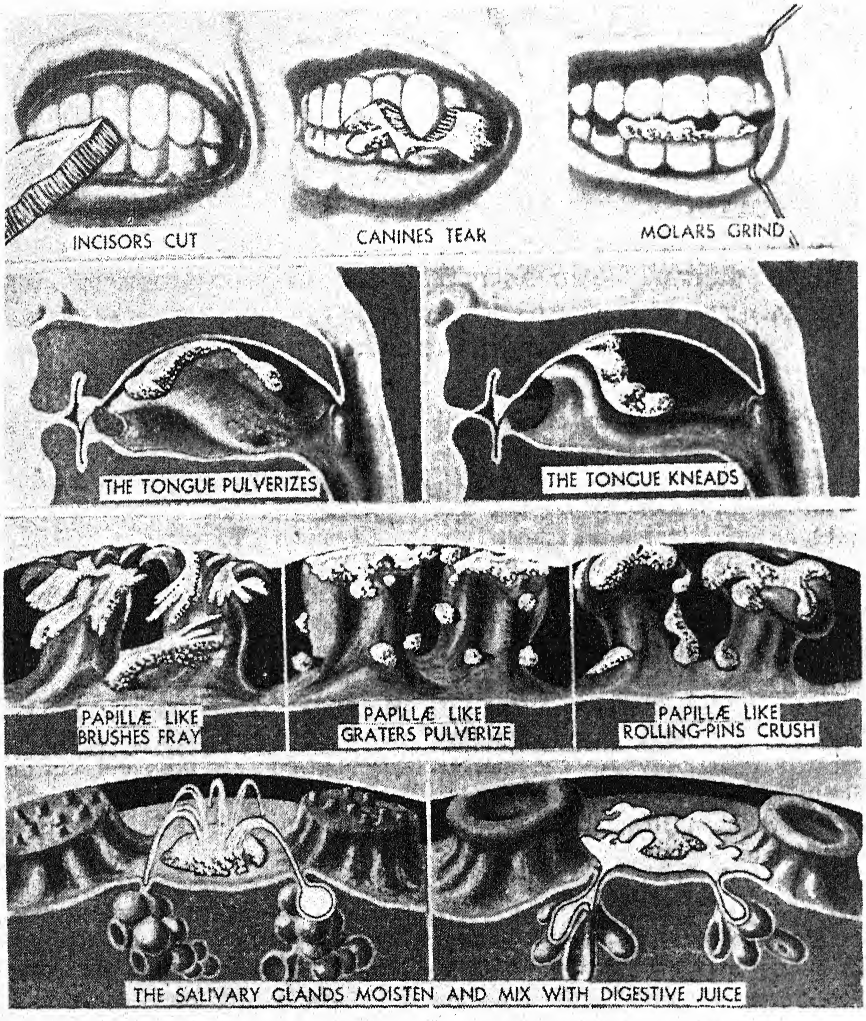


FIG. 176. *Mastication. The chewing of food—apparently such a simple process—entails the co-operation of the lips, teeth, salivary glands and the complex tongue.*

automatically when the board is moved. On its surface it bears warts and knobs of the most varied shapes: erect hard brushes, pestles, rolling-pins, knockers, and prongs. By means of its muscles the tongue presses the food against the palate, rolling it back and forth as a baker does the dough, so that the morsel, which has already been cut into tiny pieces by the teeth, is treated with brushes and bristles, crushed by pestles, kneaded with rolling-pins, and ground on small graters.

The Salivary Glands. In the course of this mechanical treatment the food is saturated with the secretions of the salivary glands. The entire mucous membrane of the mouth from the lips to the pharynx is cov-

ered with innumerable mucous glands [Fig. 176]. Three pairs of salivary glands of various sizes are located in the neighbourhood of the mouth. According to their location they are known as the parotid (in front of the ear), the sublingual (under the tongue), and the submaxillary (under the lower jaw) glands. The saliva is a mixture of the secretions of the salivary glands as well as of the glands in the oral mucous membrane.

The Regulation of Salivary Secretion. Like the majority of our organs, the salivary glands do not function mechanically, but biologically. Through their nerve supply they are subject to the control of the brain, and function in consequence of the nerve stimuli emanating from the brain centres. Let us imagine that we had made a bet to eat a lemon, and must now bite into the sour fruit. The very thought makes us swallow.

Stimulus to Digestion

On visualizing a lemon our salivary glands begin to function. Not only the salivary glands but all the digestive glands! The digestive glands do not wait until food has entered the body to begin to function, but produce their secretions as soon as the brain is stimulated by sensory impressions, or even only by ideas of food. If we see food on display, our mouths water. Such great emphasis is placed on the appetizing preparation of food because the digestive glands are stimulated by the sight of food. Odours exert an even greater stimulatory effect than optical stimuli. If one passes a kitchen and smells the fine odour of a roast, the glands begin to secrete vigorously, the stomach begins to carry out active movements; sometimes these movements are so active that they may be heard as a rumbling in the abdomen.

Salivation and Emotion. If food is shown to a hungry dog, saliva drips out of the animal's mouth. Now, if a stimulus such as a green light is applied a number of times to the dog when it receives its food, the light will become a signal for the salivary glands to begin secreting. The green light becomes a signal for the food.

Emotion Affects Appetite

If the dog is shown a series of coloured electric lights its mouth will remain dry at the sight of the red, blue, and yellow lights, but as soon as the green light appears the saliva will begin to drip from its jaws. Similarly the dog can be conditioned for a certain sound, so that saliva will appear only when this sound is heard.

Pleasant impressions aid the activity of the digestive glands, while disagreeable experiences hinder it. Anger results in a loss of appetite; fear causes one to forget to swallow; and excitement contracts the stomach.

Salivation and Nutrition. The salivary glands automatically adapt both the quantity and the nature of the saliva to the task facing them. Animals that eat moist foods produce little saliva. Fish have no salivary glands; in whales, seals, and aquatic birds they have atrophied; but in grain-eating birds the salivary glands have developed enormously. On days when a cow receives fresh feed its salivary glands secrete about 50 quarts; if it receives dry hay the quantity of saliva rises to about 200 quarts! If an individual eats 1 ounce of apple the glands produce 0.2 ounce of saliva; if the same person eats 1

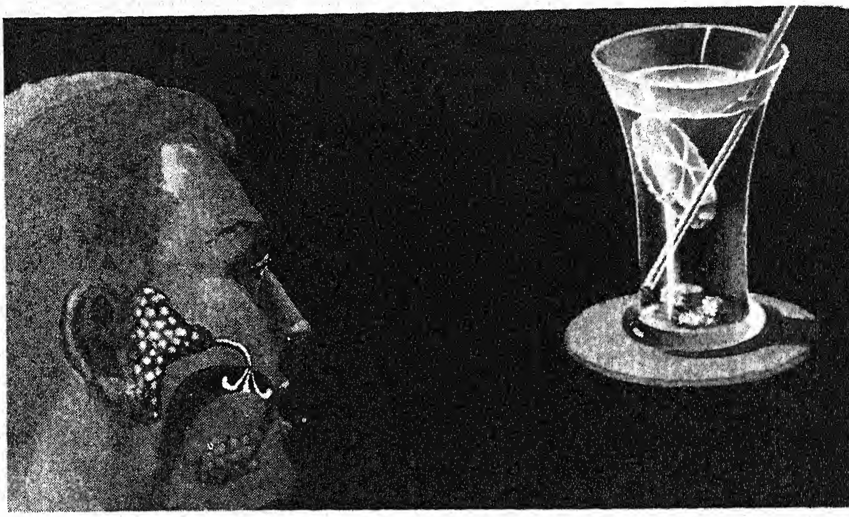


FIG. 177. *The watery saliva secreted by the parotid gland in the upper jaw serves to dilute acids. When we see a lemon and think of its sharp taste, saliva from this gland pours into the mouth in considerable quantities.*

ounce of dry biscuit, 2.5 ounces of saliva will be produced [Figure 177]. In the course of a day the parotid gland, which weighs 0.5 ounce, produces 1 quart of saliva; in the course of a lifetime it secretes 25,000 quarts of a highly active chemical, of which each drop must be laboriously synthesized by its tiny cells [Fig. 177].

The Parotid

The salivary glands are not identical in form and function. The parotid is the largest and secretes large quantities of watery saliva. The glands near the lower jaw are smaller and produce smaller quantities of mucoid saliva. The watery saliva of the upper gland serves chiefly to dilute and to moisten the food well; the mucous saliva renders the food slippery. Depending on the kind of food, the secretion of one or the other gland predominates. If we bite into a juicy apple that does not have to be moistened, the lower salivary glands secrete a scanty mucous saliva. On the other hand, if we eat dry biscuit, the parotid begins to function, producing large quantities of watery saliva containing little mucus. This alternation of function can easily be observed in one's own person. Think of " lemon " and the saliva flows from the parotid gland past the molars [Figure 177]. Conversely if one thinks of " milk " the oral cavity becomes filled from below with sublingual saliva [Figure 178]. The activity of the salivary glands is excited by reflex means.

Indirect Control

The path of this reflex is intricate—from the sensory organs to the brain, then to various perceptive centres, and after that to a special salivatory centre in the depths of the brain. Here the stimulus is transferred to nerves passing to the required gland [Fig. 179].

Dental Tartar. The average composition of human saliva is as follows: water 99.4 per cent, salts 0.2

per cent (potassium, sodium, calcium, chlorine, phosphorus, sulphur, and iron), mucus 0.2 per cent, thiocyanate 0.01 per cent, and last but not least the digestive ferment ptyalin. If saliva is allowed to stand, an iridescent layer forms on the surface. Under the microscope it is revealed as a network of calcium-carbonate crystals. Calcium carbonate, which is identical with chalk or marble, is precipitated in the mouth and deposited on the teeth as tartar. While the deposition of tartar is not in itself pathological, it does irritate the gums and favours dental infection and decay.

Starch into Sugar

The Salivary Ferment. The ferment contained in saliva is known as amylase, because it digests starch (amylum), or ptyalin. It splits the large starch molecules into dextrins and these again into malt sugar [Fig. 175]. Put a piece of bread in your mouth and let it lie there. It does not change nor does it have any taste. If it is now chewed thoroughly and mixed with saliva, it becomes sticky because the amylase has split the starch into sticky dextrin. If we wait awhile, the chewed bread becomes sweet; the salivary ferment has broken down the dextrin molecules to malt sugar, which tastes sweet.

Absence of Ferment

Since saliva contains no other ferment but amylase, all other food molecules, such as proteins, fats and carbohydrates that are simpler than malt sugar, remain unchanged. The saliva of carnivorous animals such as dogs and cats is devoid of any digestive ferment since they do not eat any starchy foods in their natural state. Similarly no ferment is found in the saliva of infants because no higher carbohydrates are contained in mother's milk. Not until the nursing period is at an end do the salivary glands of infants begin to function.

Deglutition. The teeth cut and grind the food; the saliva moistens it and facilitates mastication; and the

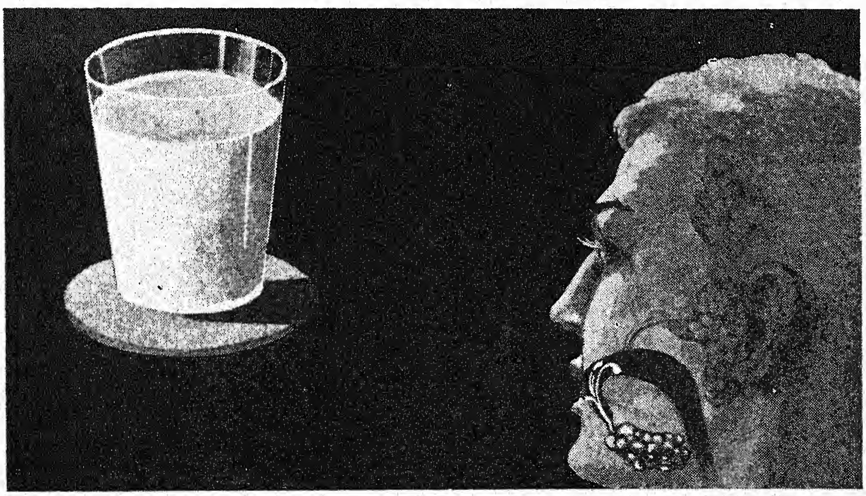


FIG. 178. *The sublingual salivary gland is situated beneath the tongue. When we think of milk, this gland begins to secrete its viscid mucus.*

tongue kneads the mass of food into a bolus which enters the gullet and passes through the œsophagus into the stomach. The act of swallowing is the work of a complex apparatus consisting of nerves, muscles, ligaments, and glands. The larynx, the uvula, the epiglottis, the soft palate, the tongue, lips, nose, lungs, the diaphragm, the abdominal musculature, and, above all, the brain participate in this half-voluntary, half-automatic act of swallowing.

The Uvula. If one looks into the back of the mouth two elevations covered by mucous membrane and reaching from the soft palate to the tongue can be seen on each side.

Swallowing

These are the faucal pillars; in the hollow between them lies a tonsil. In the centre, hanging freely in space, is the uvula [Fig. 180 (1)]. The uvula is a recent acquisition of the erect creatures man and ape. Only these two, the "primates" among animals, have a uvula. Its exact significance and function are not quite clear. The oral cavity is bounded above by the palate, consisting of a hard anterior part and a soft posterior one. The palate arches downward over the back of the mouth like a curtain. During the act of swallowing, the soft palate is raised so that it closes off the respiratory portion of the pharynx, thus preventing any food from entering the nose [Fig. 180 (b)].

After the food bolus has passed the uvula it enters the domain of the larynx, where it must pass through a region common to both the respiratory and the digestive passages. The paths taken by the inspired air and the ingested food cross above the windpipe, so that the entire arrangement appears impractical—indeed, even dangerous. The windpipe is open on top like a chimney. Above this opening passes the food bolus or swallowed fluid. However, the food must by no means fall into the windpipe, because if it does the lungs may become infected, pneumonia supervene, and life be endangered.

The Epiglottis. In order to be able to close the entrance to the windpipe, a drawbridge called the epiglottis is installed at the root of the tongue [Fig. 180 (2)]. During the act of swallowing, this drawbridge is let down, covering the entrance to the windpipe (b). Over this lowered bridge the bolus passes into the gullet. As soon as it has passed, the bridge is automatically raised. If the entrance to the windpipe is not closed in time, food may enter the larynx; then we say that it "goes the wrong way." The larynx, which is very sensitive to touch, protects itself by contracting. At the same time the individual begins to cough. There is a violent and rapid expiration of air from the chest, forcing open the larynx and carrying out with it anything lodged in the larynx.

Oral Acrobatics

Speaking and swallowing are incompatible acts, so that no one can eat and swallow simultaneously. An adult is a true acrobat, although one doesn't realize it. To carry on a conversation and to eat at the same time, to accommodate the act of swallowing to the pauses between sentences and words so that the conversation appears to be undisturbed by the act of eating, to be able to do this is truly a great achievement. We know how to do it only because we have practised it repeatedly for years. As children we prattled while we ate, just as

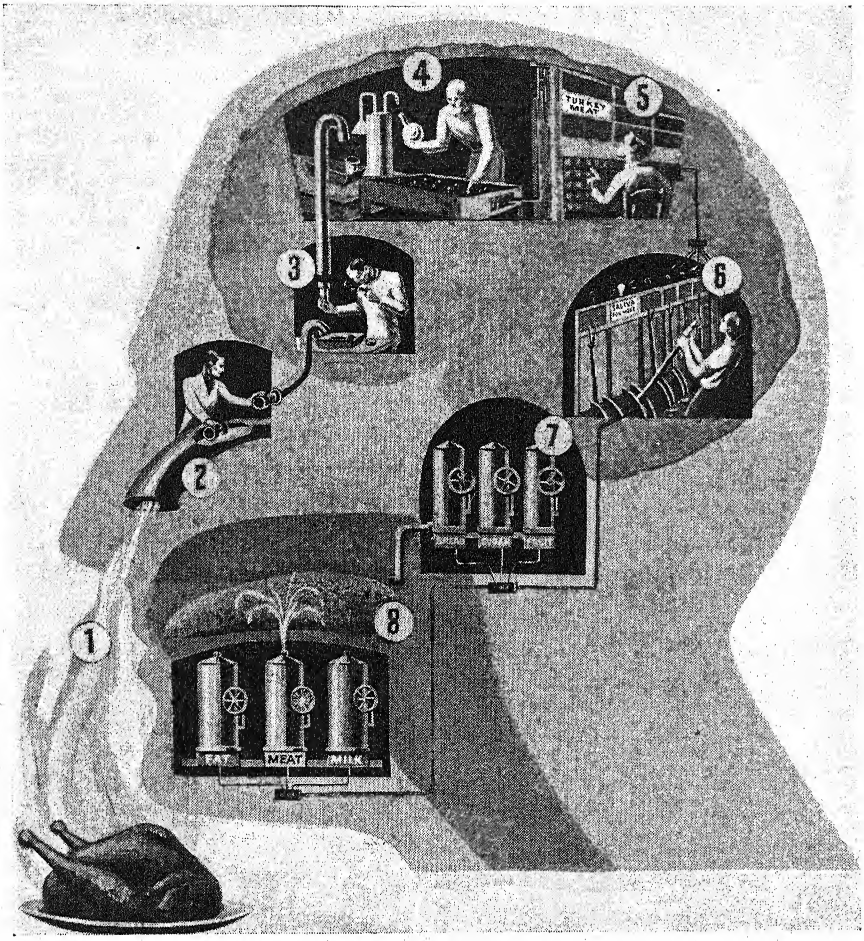


FIG. 179. *The reflex mechanism of salivation. The roast odour (1) stimulates the olfactory cells of the nasal mucous membrane (2); this stimulus is passed to the olfactory centre in the brain (3). The memory centre (4) determines that the odour is that of roast fowl, and orders the gland centre (5) to switch on a salivary gland. The order is transmitted to the switchboard (6), where the required salivary gland—sublingual—out of several (7 and 8), is promptly turned on.*

all children do; our parents forbade us to do so, just as we forbid our own children. Despite that, we did it and thus learned the great art of eating, swallowing, and carrying on a conversation at the same time. In children the food still goes down the wrong way occasionally; but adults have learned to control the acrobatic movements of the gullet. When people become weak because of old age, or in the course of serious illnesses, so that their neuromuscular mechanisms no longer react well, they begin to aspirate food particles. Many serious and exhausting sick-

nesses—above all, nerve diseases—terminate in an aspiration pneumonia—that is, a pneumonia caused by the entry of saliva and food into the lungs. The doctor fears this complication, and it is one of the aims of good nursing care to see that the patient does not aspirate any foreign substances. This object is achieved

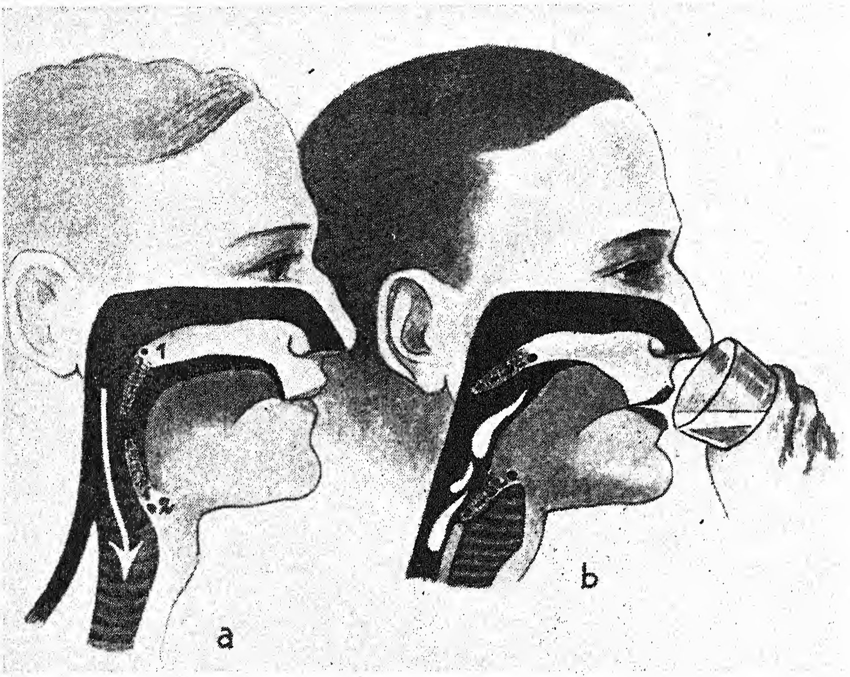


FIG. 180. *The uvula (1) and the epiglottis (2) are so situated that during the act of breathing (a) the air passage from the nose to the trachea is free. But in swallowing (b) the air passage is closed by the soft palate and epiglottis and the pathway for food is opened.*

by raising the patient while drinking, and by feeding him slowly and watching carefully to see that he swallows correctly.

The Gullet (Œsophagus). After passing the pharynx, the food bolus slides through the gullet, or œsophagus, which is about ten inches long. Like the entire digestive canal, the œsophagus is a folded elastic tube, with walls consisting of circular and longitudinal muscle fibres. The bolus does not fall through the œsophagus into the stomach, but is pushed forward by the contractions of the muscular walls. Liquids pass very quickly down the œsophagus, while solid foods travel more slowly. The larger the bolus, the more slowly does it pass down the œsophagus.

In man the passage of a bolus through the œsophagus lasts about eight seconds. The ball of hay which a horse swallows needs more than half a minute to pass from the animal's mouth to its stomach. It is easy to prove that swallowing is an active process, and not simply a passive response to the force of gravity. One can eat and drink while hanging head downwards [Fig. 181]. Most

animals also swallow upwards; in such animals as giraffes, storks, and swans the food must travel quite a distance in an upward direction. Throughout the entire alimentary canal the mechanism which moves the food is similar. The œsophagus carries out peristaltic waves; that is, the circular fibres contract behind the food bolus, narrowing the passage. At the same time the muscle fibres immediately in front of the food relax, widening the tube. Thus a continuous wave passes along the œsophagus in the direction from the mouth to the stomach. In the wall of the alimentary canal there are nerve apparatuses. Food coming into contact with the wall stimulates these nerve apparatuses, and these in turn cause the muscles with which they are connected to contract. These nerve apparatuses are never entirely at rest. Even when apparently in a state of rest, they maintain the digestive canal under moderate tension.

Artists in Swallowing. Like everything else, swallowing is an art. With patience and talent astonishing achievements can be attained. Everyone has seen sword-swallowers. Actually they are not swallowers, but, on the contrary, non-swallowers. The art of sword-swallowing consists in being able to push a sword past the larynx and through the œsophagus to the stomach without swallowing! Otherwise, by swallowing, the œsophagus would contract and cut itself.

The most famous of all sword-swallowers, Chevalier Clignot, swallowed not one but as many as fourteen sharp swords together! And he swallowed not only swords, but also a pocket watch fastened to a chain which he held. Then he let people listen to his stomach and hear the

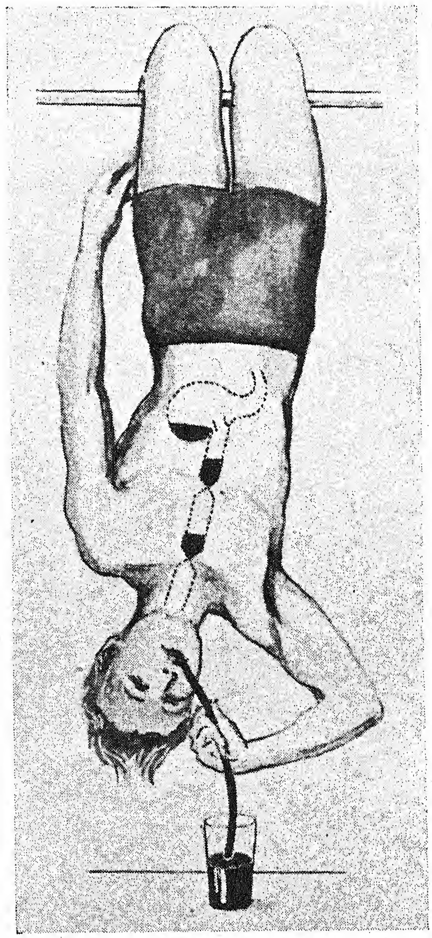


FIG. 181. *It is possible to drink while hanging head downwards, because swallowing is not merely a downward dropping of food, but a contractile, wave-like movement of the muscles of the œsophagus.*

watch tick. Psychiatric patients and feeble-minded criminals who hope to secure their transfer from prison to a hospital by swallowing objects are much bolder in swallowing foreign bodies. A psychopath fell while carrying a bottle of beer. For fear of being punished he swallowed the fragments of the glass bottle, after

wrapping them separately in paper. Several days later he vomited the paper, but the pieces of glass remained in his intestine. Not until sixteen days later did symptoms appear. A hundred and fifty pieces of glass had passed through the œsophagus, stomach, and small intestine up to the valve of the large intestine without causing any damage. Only a single small sliver had pierced the intestinal wall! The pieces of glass were removed by an operation and the man lived.

Feats of Swallowing

Large quantities of foreign bodies may be found in the organs of prisoners and psychopathic individuals. In one case more than 500 hairpins, safety-pins, keys, and links of chain were found together in a stomach! In other cases bread-knives and scissors were found! In swallowing any foreign object the most dangerous point is the crossing between the respiratory and the digestive passages [Fig. 180].

Human Ruminants. Some artists in swallowing are not only able to swallow unusual things, but like ruminants are also able to bring them up again. Usually this ability is due to a pathological dilatation of the œsophagus. The most harmless group are the water-swallowers. They can drink as much as ten quarts of water and then expel it like a fountain. In order to be original they don't swallow plain water, but water containing fish, salamanders, or frogs. In Messina a waitress made the place where she worked famous by swallowing every day, before the assembled guests, the contents of a fish-bowl containing five fish and then expelling them again. A vaudeville actor swallowed five cubic feet of gas, attached himself to a gas range and a gas chandelier, boiled eggs and tea before the audience, and consumed them under the gaslight.

Yards of Lace

The whitish substance called "ectoplasm" which pours out of the mouths of some so-called mediums during a certain type of "séance" is curtain lace which they swallow in advance in the form of a cartridge embedded in a foam-building mass, and later expel mixed with saliva and gastric juice. The "materialized ghost hands" which appear at such "séances" are nothing but rubber gloves filled with starch paste and swallowed before the séance. In order to be a good medium of this sort, one must also, among several other things, be able to swallow well!

CHAPTER XXI

The Stomach

THE STRUCTURE OF THE STOMACH. MOVEMENTS OF THE STOMACH. THE GASTRIC GLANDS. STRUCTURE OF THE GLANDS. HYDROCHLORIC ACID. PEPSIN. RENNIN. FAT IN THE STOMACH. ROAST AND EXTRACTIVE SUBSTANCES. BE HAPPY DURING MEALS!

THE stomach is a bottle-shaped bag with a volume of about 61 cubic inches, situated rather transversely in the upper part of the abdomen [Fig. 169 (a)]. Its larger end is turned to the left. Opening into its upper border through the cardiac orifice is the œsophagus. Like the entire digestive canal the stomach consists of three firmly united layers [Fig. 197]: the external peritoneal covering (i), the middle muscular layer (e-h), and the inner mucous membrane (a-d). The stomach can be described as a muscle sac lined with mucous membrane. At the entrance to the stomach as well as at its exit the musculature is thickened to form a powerful circular muscle which by its contraction keeps the passage closed except at the moment when food is passing into and out of the stomach.

Protecting the Stomach

The entrance from the gullet into the top of the stomach is known as the cardia; the exit from the stomach to the succeeding portions of the alimentary canal is called the pylorus. Both orifices open only under certain conditions — the cardia only when a delicate stimulus impinges upon it such as is exerted by a thoroughly masticated, well-formed food bolus. Strong stimuli cause it to close. If some coarse object which might damage the stomach passes through the œsophagus, the cardia contracts spastically and refuses to let the intruder enter. If a hard tablet is swallowed, for instance, it does not simply slide into the stomach, but remains in the œsophagus above the spastically contracted cardia, with the result that one experiences an unpleasant sense of pressure in the upper abdomen.

Harmful Substances

Then the tablet gradually dissolves in the moist tract, the cardia permits small portions of the dissolved mass to pass through, and the feeling of pressure disappears. Like a true watchman the cardia also tries to prevent the entry of all biting, caustic, or stinging fluids. If one drinks aerated water or beer, it likewise collects above the stomach and creates a sense of pressure. If one drinks a corrosive fluid such as hydrochloric acid or phenol, it remains above the carolia, and it is there that the worst burns are found.

The interior of the stomach is ingeniously constructed. The larger end of the stomach, into which the gullet opens, lies beneath the diaphragm, where it forms a dome-shaped space. In those who lead a temperate life this space is never com-

pletely filled. In this space is air swallowed during mastication, or gases arising from ingested food or liquids. The carbon dioxide of beer, soda water, etc., ascends into this space. When a person belches, he evacuates the gas from this space. The muscle fibres of the stomach wall

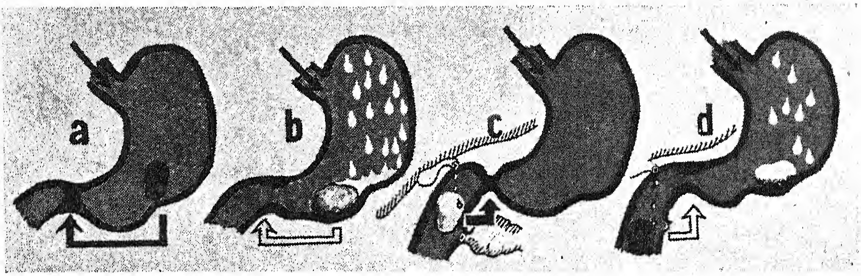


FIG. 182. *How food regulates the pylorus. The food arriving in the stomach is alkaline, owing to the saliva, and consequently closes the pylorus (a). After the food has been acidified by the gastric juice the pylorus opens (b). On entering the small intestine the acidity of the food exerts a retrograde action (c), causing the pylorus to close. After the food has become alkaline in the intestine, the pylorus relaxes (d) and admits more food into the intestine. In this way, the food controls its own passage through the stomach.*

are arranged in folds, so that the interior presents the appearance of the relief map of a mountain range. Between the cardia and the pylorus passes a channel, the "stomach street," along which the "traffic" of the stomach passes. After drinking, the fluid passes directly from the cardiac orifice along this "street" to the pylorus and enters the small intestine. Small quantities of fluid pass through the stomach almost without stopping, even when the latter is full. The views frequently expressed that drinking during a meal is unhealthful, that the fluid makes one bloated, or dilutes the gastric juice, do not apply to a healthy stomach.

Movements of the Stomach. Like all smooth fibres the muscle fibres of the stomach wall possess a certain tension (tonus), so that the stomach is elastic. If it were simply an inanimate sac, the weight of a meal would cause it to sink down. This actually occurs in stomachs of which the tonus is decreased. After a meal an atonic stomach looks like a stocking and hangs down from the pit of the stomach to the pelvis. In healthy people, however, the stomach unfolds in all directions in response to the entering food until the normal capacity of the organ is reached. It expands gradually like a balloon without changing its original form. When food enters the stomach its glands begin to produce an acid secretion. Stimulated by this secretion, the walls begin to move in the form of peristaltic waves. The upper part of the stomach remains relatively quiet. The gastric juice mixes with the semi-liquid food mass. The floor of the stomach, upon which the food lies, moves in waves resembling those with which a photographer moves the developing fluid over a plate in order to attain the highest degree of chemical action. Both photographer and stomach want to obtain the same result—namely, thorough mixture so as to achieve the greatest chemical action—and consequently both em-

ploy the same method of doing so.

The food masses that enter the stomach do not lie about anyhow, but arrange themselves in definite layers. The first food eaten is deposited next to the wall of the stomach, and subsequent masses of food upon the first layer, so that the most recent food is situated towards the centre of the stomach. The entire arrangement resembles that of a layer cake. By means of the wave movements of the stomach wall these layers are thoroughly churned and mixed with the secreted gastric juice.

Acid and Alkali

The food which has been well mixed with gastric juice flows to the deepest part of the stomach near the pyloric sphincter. The latter is normally closed, and opens only under certain circumstances. The alimentary canal consists of four large divisions: mouth and œsophagus, stomach, small intestine, and large intestine. The chemical character of each of these sections differs from that of its neighbours. The mouth is alkaline owing to the saliva; the gastric juice makes the stomach acid; because of its secretions the small intestine is again alkaline; and finally the contents of the large intestine are acid because of the activities of the bacilli in it.

This alternation of alkalinity and acidity is of particular importance in regulating the traffic of the alimentary canal [Fig. 182]. If a food morsel which is alkaline comes into the neighbourhood of the pylorus, the latter closes (a). Conversely, if the morsel has been sufficiently saturated with gastric juice, thus proving that it is sufficiently digested, the pylorus opens (b). Hardly does the morsel pass the pylorus and touch the alka-

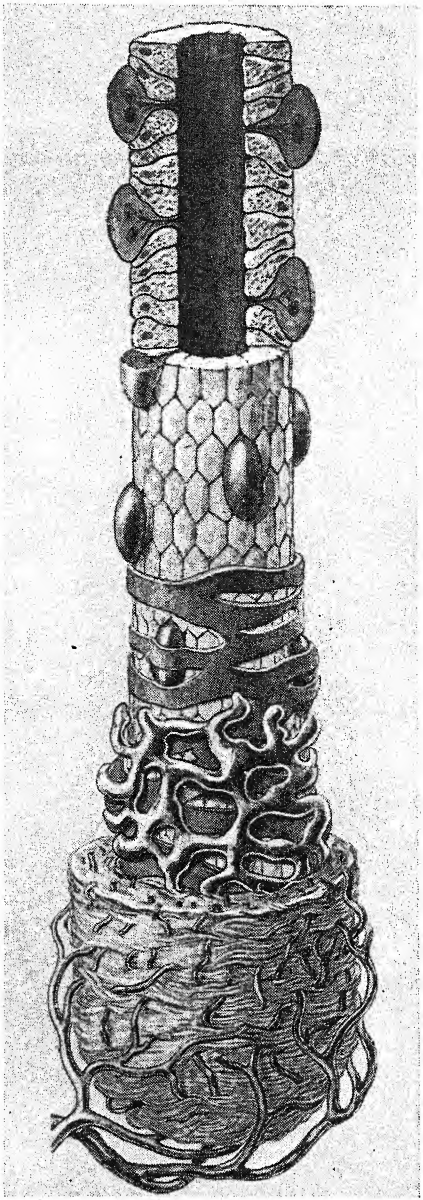


FIG. 183. *One of the five million digestive glands contained in the mucous membrane of the stomach which secrete pepsin, rennin, and hydrochloric acid. The larger, dark cells (upper part of picture) are the cells which produce this acid.*

line mucous membrane of the small intestine with its acid when the pylorus closes behind it (c). If the food mass is sufficiently saturated with the secretions of the small intestine so that it loses its acid character, the stimulus which causes the pylorus to close disappears and it opens again (d). By means of this mechanism, which reminds one of a railway switch, the body makes sure that only small quantities of food will pass from the stomach into the small intestine, and only then when they have been adequately mixed with gastric juice.

Wave-Machine

By closing the pylorus from the small intestine in this way, the guarantee is given that no new food will enter from the stomach before the small intestine has finished with its contents. In fact the transportation of food from the stomach to the intestine proceeds as precisely as railway traffic. Four minutes after the arrival of the first morsel of an easily digestible food, such as a soft-boiled egg, the wave-machine of the stomach begins its movements. Soon thereafter the pyloric sphincter relaxes for a moment, permitting about one cubic centimetre of liquefied food to pass through, and closes again. Then successive portions follow regularly at ten-second intervals. The wave-machine works for hours until the digested mass has been transported from the stomach into the intestine.

The Gastric Glands. On examining the mucous membrane of a calf's stomach with a magnifying glass, one sees the punctate openings of the glands that secrete the gastric juice. Each cubic centimetre contains about 100 glands, so that there are 5 million glands in the wall of the stomach. These glands are very industrious, producing about 3 quarts of secretion daily, and in the course of a lifetime approximately 100,000 quarts of a highly concentrated fluid. A stomach gland is shaped like a fountain-pen. It is a narrow tube lined with gland cells and opening into the stomach [Fig. 183]. The majority of the cells are small and light-coloured. Their protoplasmatic granules secrete two ferments, rennin and pepsin. Between them are large, dark cells called parietal cells. The parietal cells produce hydrochloric acid.

Structure of the Gastric Glands. Figure 184 is a composite representation of the glands of the mucous membrane of the stomach, highly magnified. At (a) we see some of the glands in cross-section. At (b) is a more detailed view of a gland, from which we can see that its wall contains two kinds of cells. The more numerous, light-coloured cells produce pepsin; the large, laterally-situated, darker cells produce hydrochloric acid. At (c) is a gland of this kind in active secretion, and at (d) are the nerves that activate the gland and stimulate it.

Gastric Secretions

The view of the gland at (e) shows only the cells that produce hydrochloric acid, with their characteristic ducts that open into the lumen (or canal) of the gland pit. At (f) are seen lymph-vessels that pass downward between the glands and form plexuses around them, as shown at (g); (h) represents a plexus of contractile cells around the gland, which by contracting expresses the gland's contents. At (i) is the connective tissue surrounding the gland; (k) shows the ascending arteries (light)

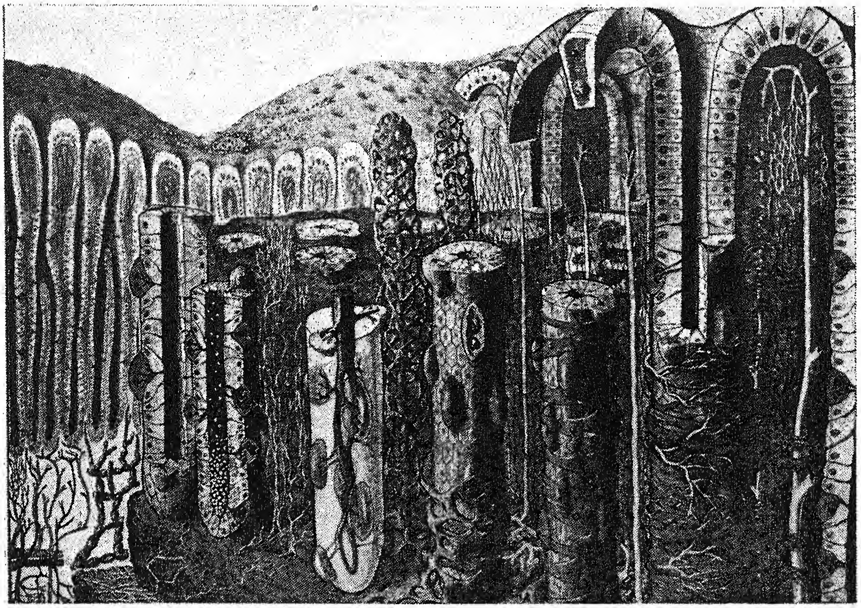


FIG. 184. *The glands of the stomach are among the most active in the body, producing daily about three quarts of gastric juice. This juice consists of hydrochloric acid, with a number of ferments, including rennin and pepsin. Here is a composite picture of some of these glands, highly enlarged, revealing their minute but highly complex structure.*

and the descending veins (dark) between the glands. The three chief constituents of the gastric juice are hydrochloric acid, pepsin and rennin.

Hydrochloric Acid. Hydrochloric acid has five functions:

1. It activates pepsin. The cells do not secrete pepsin in an active form, but in an inactive preliminary state. Not until it comes into contact with hydrochloric acid is the active ferment pepsin produced.

2. It accelerates the action of pepsin. If one takes two pieces of boiled egg, placing one directly into gastric juice and the other first in hydrochloric acid, the second piece will be digested more rapidly.

3. Hydrochloric acid stimulates the muscle fibres of the stomach wall, and aids the movements of the stomach, thus promoting digestion.

4. Hydrochloric acid activates the digestive apparatus in the neighbouring sections of the intestinal tract. As soon as the stomach secretes hydrochloric acid, not only the stomach but also the duodenum begins to exhibit peristaltic waves, the liver secretes bile, and the pancreas, pancreatic juice.

5. Hydrochloric acid disinfects. If chopped meat is placed in a glass of water and allowed to stand in a warm spot, putrefaction develops rapidly. However, if hydrochloric acid is first added to the water, putrefaction does not appear, because hydrochloric acid destroys fungi and bacilli. There is no putrefaction in a healthy stomach. We ingest billions of bacilli daily with our food, yet they

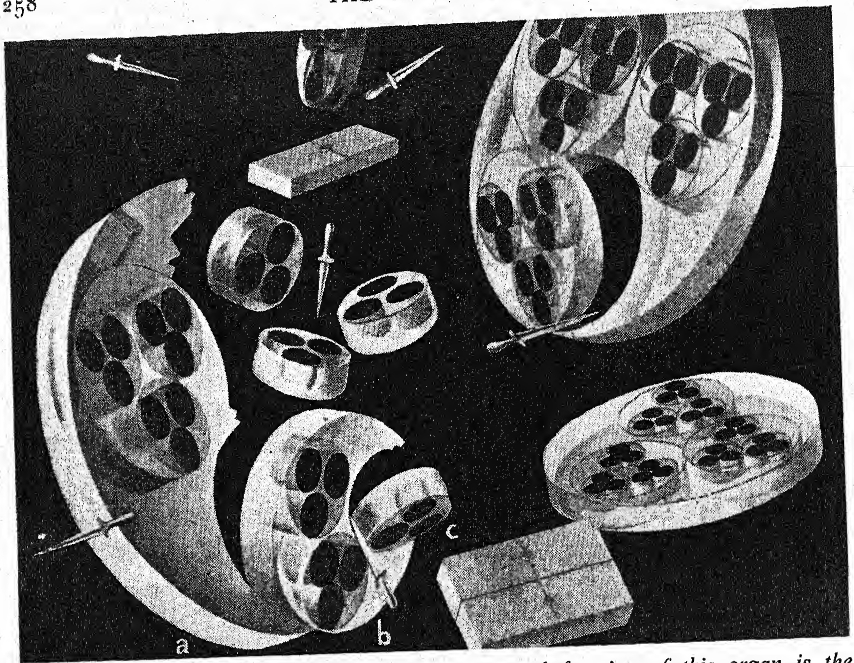


FIG. 185. *Digestion in the stomach. The principal function of this organ is the digestion of protein. The large protein molecules (a) are broken down and chemically altered by the enzyme, pepsin, first into albumoses (b) and then into peptones (c). There is no further breakdown of the protein molecule in the stomach. (Compare this illustration with Figs. 175, 194 and 202.)*

do not harm us because they fall into a gigantic lake of hydrochloric acid and pepsin in the stomach and simply die there.

Pepsin. Hydrochloric acid is not a ferment, but rather an "activator." The gastric glands produce three ferments, of which pepsin is the most important for the adult. As stated above, pepsin is secreted in a preliminary form and changed into active pepsin by hydrochloric acid. Pepsin initiates the digestion of the large protein molecule [Fig. 185]. First it cuts the protein plates (a) into large pieces, called albumoses (b), and then cuts the latter into peptones (c). Food that enters the stomach as protein leaves it through the pylorus after chemical change into peptone.

Rennin. The two other ferments of the gastric juice are special ferments for the digestion of milk. That the human body has special ferments for the digestion of milk is a peculiar fact, apparently connected with man's mammalian character. The newborn baby is reared on its mother's milk. In order for its young body to be able to digest the relatively large quantities of milk necessary for growth, the digestion of the milk is made doubly certain by means of the special ferments.

Rennin splits the protein of milk, which is known as casein, into two smaller protein molecules, paracasein and whey-protein. The former combines with the calcium of milk to form a calcium protein compound,

which we call cheese. Cheese is a combination of milk protein and calcium. When an infant regurgitates, it does not bring up milk, but cheese. The second milk ferment attacks the fat of milk. If a person eats six different kinds of fat during a meal—for instance, sardine oil with the hors-d'œuvres, olive oil in the salad, fish oil, the fat of the roast, vegetable fat in nuts, and butter—only the last-named fat, since it is a milk product, will be digested in the stomach.

Fat in the Stomach. Since the stomach does not digest any fats except milk fat, so that the others are first digested in the lower sections of the intestine, we are right in saying that fatty foods take longer to digest. Large quantities of fat slow down gastric digestion, because the fat covers the other foods and renders it difficult for the gastric juice to come into contact with the food.

Fat Hard to Digest

Generally, the more fat there is in a food, the longer does it remain in the stomach and the harder is it to digest. Tea flows through the stomach almost without stopping. Milk with a high fat content remains there over an hour. A lean plaice is quickly digested, but fat pork or sardines in oil remain in the stomach much longer [Fig. 187].

Roast and Extractive Substances. Roast substances are those aromatic substances that arise as a brown crust when bread, meat, or potatoes are roasted. Extractive substances are those substances removed from vegetables and meat when they are boiled, and contained in broth. Meat extract, bouillon, the expressed juice of vegetables, and gravies are rich in extractive substances. Roast and extractive substances [Fig. 186 (1)] stimulate certain groups of cells in the lower section of the stomach (2), causing them to secrete a substance which does not enter the stomach but passes into the blood vessels (3). The

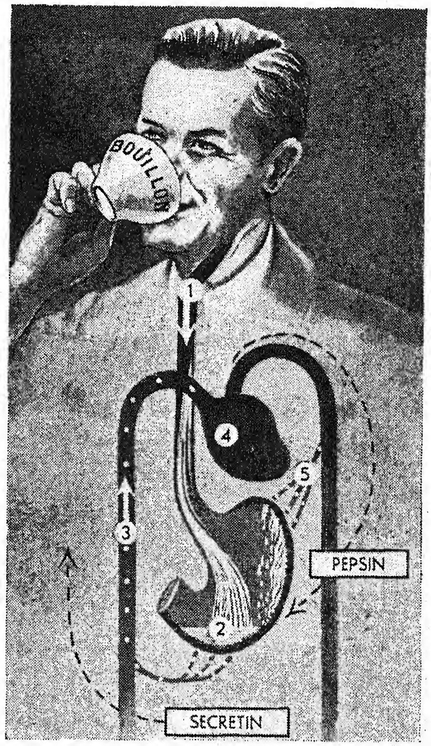


FIG. 186. *Bouillon, or meat extract, is rich in extractive substances, which are valuable in digestion because they stimulate special cells in the gastric wall (2) to produce a hormone (secretin). The latter enters the circulation (3 and 4) and in its turn stimulates the stomach glands (5) to secrete large quantities of digestive juice.*

blood carries this substance around in the body (4) to all the organs, including the glands in the upper section of the stomach (5). Here it stimulates the cells to produce large amounts of very powerful gastric juice. This stimulating substance is termed secretin, since it stimulates

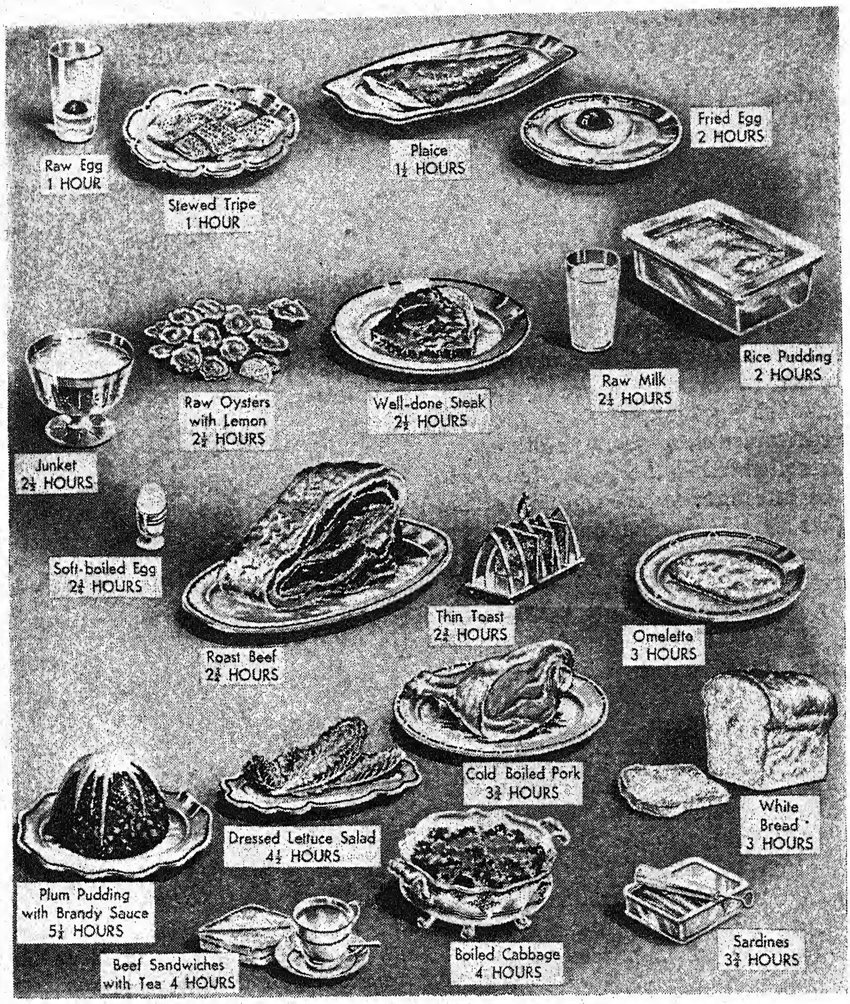


FIG. 187. *Digestibility. The rapidity with which food passes through the stomach is an indication of its digestibility. Foods such as raw eggs, steamed plaice or rice pudding, which leave the stomach fairly quickly, are readily digestible. Fat foods remain a long time in the stomach, because the fat-splitting action of gastric juice is slight.*

secretion of the gastric glands. The stimulating action of the extractive and roast substances explains the custom of beginning a meal with bouillon or canapés on toast. The custom of drinking small amounts of a dry wine is also based upon the same fact. In the first place these wines also contain bitter extractive substances, and secondly alcohol in small quantities mobilizes the secretin of the gastric wall. Human beings generally are unacquainted with secretin, and do not know how bouillon, Tokay, and caviar canapés act in the stomach; but they do know

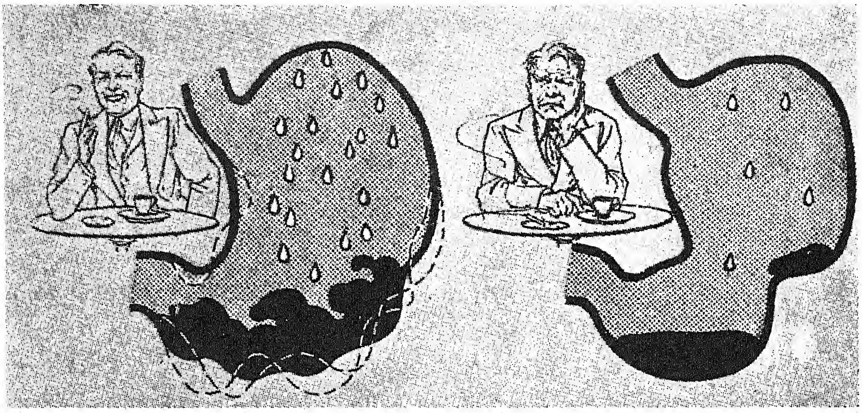


FIG. 188. *Eat your meals with a light heart! The stomach of the contented man is active and secretes digestive juice copiously; but when a person is worried or depressed the stomach becomes sluggish and deficient in secretion, causing a feeling of uneasiness and excessive fullness in the abdomen after meals.*

what is good or bad for them, and what does or does not agree with them. Thus, independently of science, they have collected their experience and created the " ritual " of the meal which the discoveries of science have justified.

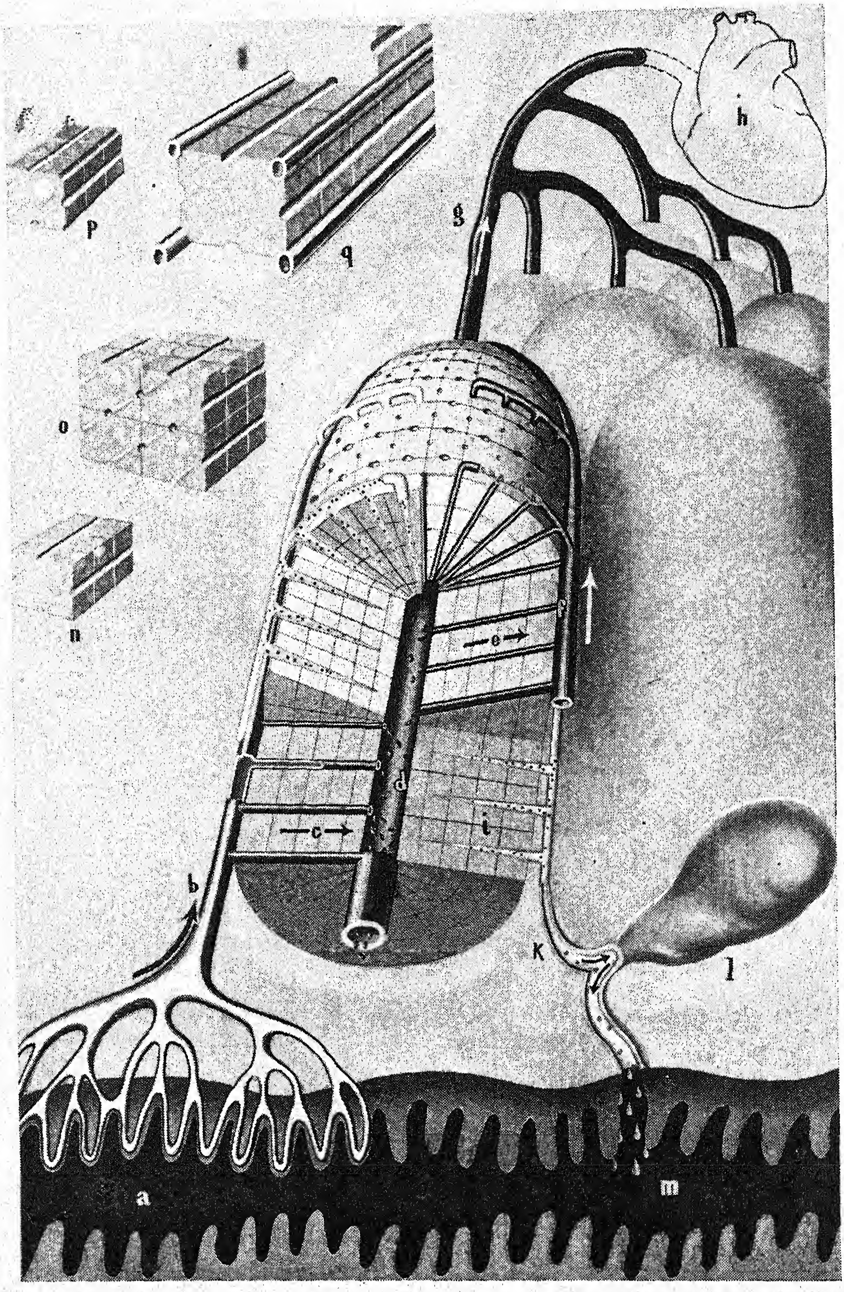
Anticipation Helps Digestion

Be Happy during Meals! The gastric glands also resemble the salivary glands in that they do not wait for a direct stimulus before beginning to function, but are activated by emotional changes, joy, desire to eat, sensory impressions, odours, and imagination, before the food itself arrives.

Thus, if one places food in a dog's mouth without permitting the animal to see it, the food is swallowed but it remains lying in the dog's stomach without a concomitant secretion of gastric juice. On the other hand, if one holds a bowl of food before the dog but prevents it from eating, the animal's stomach is filled with a big lake of gastric juice. Ideas have a greater influence upon the character of the gastric juice than the food itself! A disturbing thought suffices to interrupt the digestive machinery within us. For the stomach to receive food freely, to cover it with gastric juice by means of vigorous movements, a meal must be eaten without any disturbance and in good spirits. The table must be appropriately set, the food appetizingly prepared and served, and the conversation interesting but not too serious. All unpleasant news should be avoided during a meal [Fig. 188].

Eat With Enjoyment

If you wish to keep your stomach healthy, learn the art of eating! Don't read a newspaper while having your soup, and don't think of the matters to which you must attend in the afternoon while chewing your meat. The hour of eating should be an hour of forgetting, devoted entirely to the enjoyment of food. This is the best medicine for the maintenance of youth, health and vitality.



A LIVER CONE—FILTER AND FACTORY

FIG. 189. *A schematic drawing, on a greatly enlarged scale, of a liver cone. Its cells help to filter the blood and also make bile from it. The liver contains about a million such cones.*

CHAPTER XXII

The Liver and the Pancreas

THE LIVER—THE FILTER BETWEEN THE INTESTINE AND THE HEART. THE STRUCTURE OF THE LIVER. THE DISINTEGRATION OF THE BLOOD CELLS. THE "HUMANIZING" OF THE FOOD. THE DETOXIFICATION OF THE FOOD. THE LIVER AS A FLUID RESERVOIR. BILE. GALL-BLADDER AND GALL-STONES. LIVER AND EMOTION. THE PANCREAS AND ITS FOUR FERMENTS. THE ISLANDS OF THE PANCREAS.

AFTER leaving the stomach the partially digested food passes into the small intestine. Here, almost directly behind the exit of the stomach, two digestive glands, the liver and the pancreas, empty into the small intestine.

The liver is the largest gland of the body and, next to the approximately equally heavy brain, the largest organ of the body. It weighs about three pounds on the average and fills the entire space under the right half of the diaphragm [Fig. 169 (i) and Fig. 190].

A Filter

The liver is necessarily so large because it not only manufactures digestive juices as do the stomach and the salivary glands, but in addition is also a filter in which all the food received from the intestine, with the exception of fat, is treated by chemical processes. The liver is placed as a filter between the intestine and the heart [Fig. 189]. The food substances absorbed by the intestinal wall pass into hundreds of thousands of delicate little blood vessels. These unite to form a large vessel which enters the portal of the liver and is called the portal vein [Figs. 190 (a) and 198 (P)]. The portal vein ramifies in the liver and breaks up into a million tiny vessels; next to the lungs the liver is the most vascular organ. For this reason larger operations on the liver, just as on the lungs, can be performed only in rare, exceptional cases. Liver wounds are usually fatal because the individual quickly loses too much blood. The liver is a blood-filled sponge which absorbs the food digested in the intestine.

The Structure of the Liver. The mass of the liver is composed of roughly a million cones each about one millimetre in length. Figure 189 shows such a cone in the centre of the picture. The blood, rising from the intestine (a-b), flows through it (c-d-e), and leaves by way of (f), flowing through the hepatic vein (g) towards the heart (h).

The Liver Cells

During this journey through the liver cones the blood is so finely divided that it flows in extremely delicate capillaries right next to the cells. The liver cells are cubical in shape. A cross-section of a liver cell shows that the edges and sides are grooved (p). When the cells lie crowded together in the liver, these

grooves unite to form tubes. At the edges of the cells the grooves unite to form blood channels (q), while those on the sides form tubes within which the bile flows (n, o). Not only do the liver cells filter the blood arising from the intestine, but at the same time they manufacture bile from the substances contained in the blood. In order to grasp and understand the structure of the liver one must keep in mind the remarkable fact that the bile flows to the intestine in an opposite, retrograde direction. The blood rises from the intestine to the liver and flows towards the heart (a-b-c-d-e-f-g-h). The bile manufactured in the liver flows downward towards the intestine (i-k-l-m). These two streams, the rising blood-stream of the portal vein and the descending stream of bile, pass each other like the ascending supply of drinking water in a house, and the descending waste.

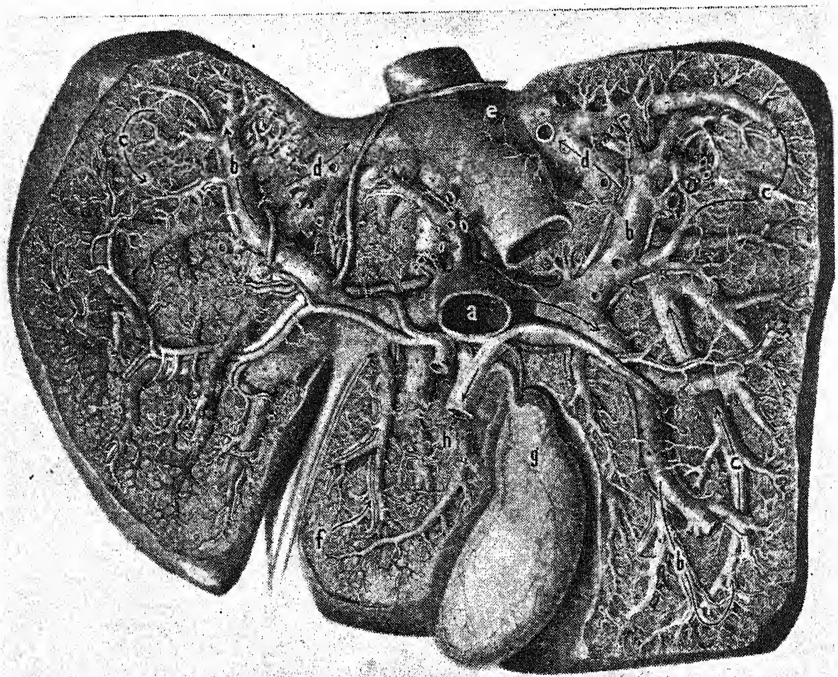


FIG. 190. *A dissection of the liver. The blood enters the liver through the portal vein (a), which divides into numerous terminal branches (b, c), from which the substances carried by the blood pass to the liver cells. The filtered blood collects in the hepatic veins (d, e), and afterwards passes to the heart. The bile prepared by the liver cells flows through the small bile ducts into the gall-bladder (g) and thence through the common bile duct (h) into the intestine. Among the numerous functions of the liver is the conversion of food into human protein.*

The Disintegration of the Blood Cells. The preparation of bile is only one of the many activities of the liver cells. Figure 137 depicts life in a hepatic vessel. Polypoid cells fish

out the old blood cells and prepare bile from them.

The "Humanizing" of the Food. The liver is the place where the food is reconstructed and foreign protein is rebuilt to form human protein. In the intestinal canal the protein of cow's milk or spinach is broken down to its simpler components; in the liver the fragments are rebuilt into human protein.

Life Saver

It is a fact that the intravenous injection of foreign proteins or of protein derivatives is followed by a reaction that varies from a mild rise in temperature to a state of extreme shock associated with collapse of the vasomotor regulation of the circulatory system. Even the products formed in the intestine during digestion—the peptones, for example—have an action of this kind when injected into the blood-stream, without first passing through the filter of the liver and being rendered harmless. The liver saves our lives daily.

Detoxification of Food. Toxic substances such as nicotine, caffeine, morphine, and atropine are bound by the cellular protoplasm of the liver and transformed into harmless compounds. Bacilli are caught and eaten by the liver cells. These achievements can be proved by numerous experiments. If a solution of soap is injected into an animal's circulation above the liver, the animal dies; if an equal quantity is injected into the portal vein so that the soap solution must pass through the liver, nothing happens to the animal. The liver turns the soap into fat—animal or human fat! If a fatal dose of atropine is injected into the general circulation of an animal, it dies of atropine poisoning. Yet four times as much atropine can be injected into the portal vein, and the animal will remain alive!

The Liver as a Fluid Reservoir. Because of its position between the intestine and the heart, the liver acts as a dam for all ingested fluids. If an individual drinks a large quantity of fluid, the liver swells soon thereafter. Excessive imbibition of fluid may over a long period produce a liver as hard as a board. Many habitual drinkers have sick livers, owing to the fact that they partake of strong alcoholic beverages such as whisky, which is a poison and damages the liver cells. The liver also swells when the function of the heart is impaired, because owing to the inability of the heart to pump the blood through the circulation, it is dammed back in the veins, thus distending the liver (passive congestion of the liver).

Minute Laboratories

The liver cell is one of the most industrious and capable cells of the body. Our minds are utterly unable to comprehend how a microscopically small dot—100,000 could find room in a crumb—can carry on simultaneously so many and such diverse functions as the breaking down and reconstruction of carbohydrates, protein, and fats, chemical processes of the most complex kind such as the detoxification of poisons, the capture and digestion of bacilli and blood cells, and the production of highly active extracts and hormones.

Bile. From the substances which it removes from the blood as the latter flows by, the liver cell manufactures the digestive fluid, bile. Bile, or gall as it is commonly known, is not a ferment. It is the only digestive juice that contains no ferment.

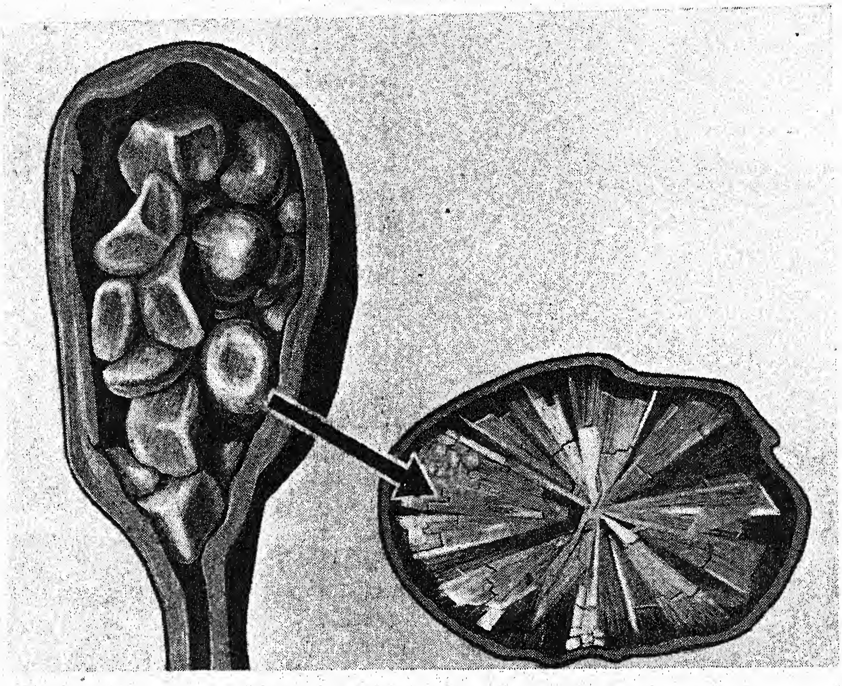


FIG. 191. *Gall-stones. These are hard concretions of mixed organic and mineral matter which sometimes accumulate in the gall-bladder in large numbers (Left). A gall-stone impacted in the bile duct may cause severe pain, while the diverting of the obstructed bile into the blood-stream may result in jaundice. On the right is a cross-section through a gall-stone, showing its structure, which resembles that of an agate.*

Fresh bile is a golden yellow fluid which rapidly loses its colour when exposed to the air and turns dark green. It has such a bitter taste that the expression has arisen: " as bitter as gall." Bile contains two pigments, known as bilirubin, or bile red, and biliverdin, or bile green, which the liver cell prepares from the pigment of the blood, and two bile acids that are actually the active components of the bile. These acids have three principal functions:

1. The bile acids activate the ferment of the pancreas. Just as hydrochloric acid activates pepsin—that is, transforms the inactive preliminary stage of pepsin excreted by the gastric cells into the active pepsin—so the bile acid changes the inactive form of the fat-splitting ferment of the pancreas into the active form.

2. The bile acids emulsify fat. They divide the large fat drops contained in the mixture of digested foods into very fine droplets. On examining milk under a microscope fine droplets may be seen floating about in it. Milk is a microscopically fine mixture, an emulsion of fat. If the milk is centrifuged, the fat droplets flow together and collect on the walls of the vessel as butter. In the intestine the reverse takes place; here butter is turned into milk again. Under the influence of the bile all ingested fats are changed into milk soon after leaving the stomach.

This process could be called the "lactification" of fat. Without this "lactification" fat could be absorbed by the body only in small traces. If the bile is prevented from entering the intestine in animals they become emaciated even though they are well fed. As a result of their internal fat hunger they are extremely ravenous.

3. The bile acids make the fat droplets sticky. When a painter wants to apply oil paint to a fatty surface, he mixes the paint with ox gall. Then the paint sticks. After being mixed with bile the fat sticks to the moist intestinal wall.

The presence of bile in the intestine is necessary for the normal absorption of fat. If the supply of bile is cut off by the occlusion of the bile ducts, the utilization of fat drops from about 98 per cent to 40 per cent. After being emulsified, the fat is absorbed from the intestine and passes into the lymph-vessels. A few hours after a meal rich in fats, the intestinal lymphatics may be seen to be distended with a milky fluid, which is known technically as chyle. From the lymphatics the chyle passes into the thoracic duct, the main lymph trunk of the body, and from it into the blood-stream.

Gall-bladder and Gall-stones. The bile does not flow directly from the liver into the intestine, but first into

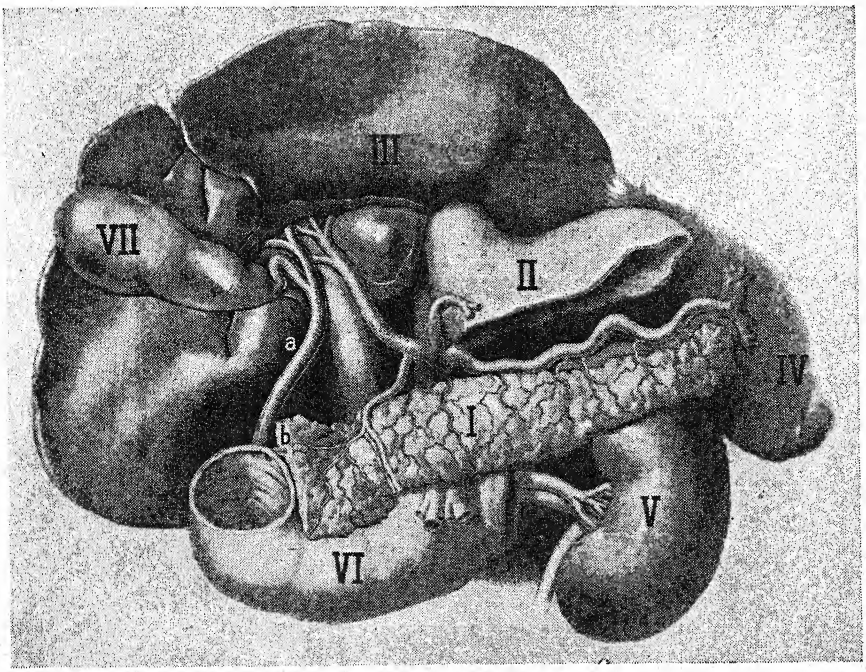


FIG. 192. *The pancreas (I) lies partly concealed between the stomach (II)—much of which has here been removed—the liver (III), which has been pushed upward, the spleen (IV), the left kidney (V), and the small intestine (VI). The vessel (a) is the common bile duct; (b) is the point of entry of the pancreatic duct; (VII) is the gall-bladder. The pancreas secretes important digestive substances, as well as the hormone, insulin, which is the product of its so-called "island" cells.*

the gall-bladder, a bag shaped like a tobacco pouch. It is attached to the inferior surface of the liver and holds approximately 2 cubic inches [Fig. 169 (k)]. The bile duct connects it with the intestine. This duct is usually closed. If a portion of digested food passes the point where it opens into the intestine, however, it presses on a nerve switch. The gall-bladder contracts, the bile duct opens, and a portion of bile flows over the food [Fig. 190 (g, h)].

The gall-bladder is a dispensable organ. Many animals have no gall-bladder—for instance, the horse, elephant, camel, pigeon, etc. As is well known, stones form quite easily in the human gall-bladder. At the age of thirty one person in a hundred has gall-stones, at fifty one in ten, and at sixty-five every fifth person—but not everyone with stones suffers because of them. Gall-stones come to the attention of their owner only when they hinder the normal flow of bile or cause pain. If a stone becomes incarcerated in the narrow duct connecting the gall-bladder with the intestine, a violent spasm or gall-stone colic is produced. The bile collects in the liver and passes into the blood. As a result the affected individual acquires a greenish-yellow colour; he is jaundiced.

Sinister Beauty

Gall-stones are occasionally found as large as a hen's egg, yet they are often so small that the gall-bladder is filled with as many as two hundred small stones. Because they arise in a very similar manner, the structure of gall-stones is like that of agates. When gall-stones are sectioned the cut surface is frequently a beautifully iridescent ochre yellow or a shining malachite green. Gall-stones are very beautiful—when held in the hand, but not when carried in the gall-bladder [Fig. 191].

Liver and Emotion. The liver is also influenced by ideas and emotions, just like the mouth and the stomach. Let us imagine a large savoury omelette, served piping hot. Not only must we swallow, while reading this sentence, because the salivary glands have filled the mouth with saliva, not only does gastric juice collect in the stomach, but a portion of fresh bile also flows from the liver into the gall-bladder. Indeed, the liver is subject to the influence of the emotions to a greater degree than any of the other digestive glands.

Jaundice

The influence exerted by emotion on liver function is quite remarkable, and has not yet been entirely elucidated. Thus, a feeling of joy produces a moderate increase in the flow of bile, sorrow increases it considerably, while anger results in a stoppage of the flow. If a person is overcome by a strong feeling of loathing and nausea, the entire biliary system contracts: the common bile duct which carries the bile to the intestine, the gall-bladder, and the small biliary passages in the liver itself. The bile is dammed back and may even pass into the blood vessels if the backward pressure becomes too great.

Should this occur, the individual becomes jaundiced. The most frequent cause of jaundice is a catarrh of the small intestine and the biliary passages. The mucous membrane swells, occludes the bile duct, and dams back the bile, which passes into the blood. Since the digestion of fat is impossible without bile, a fat-free

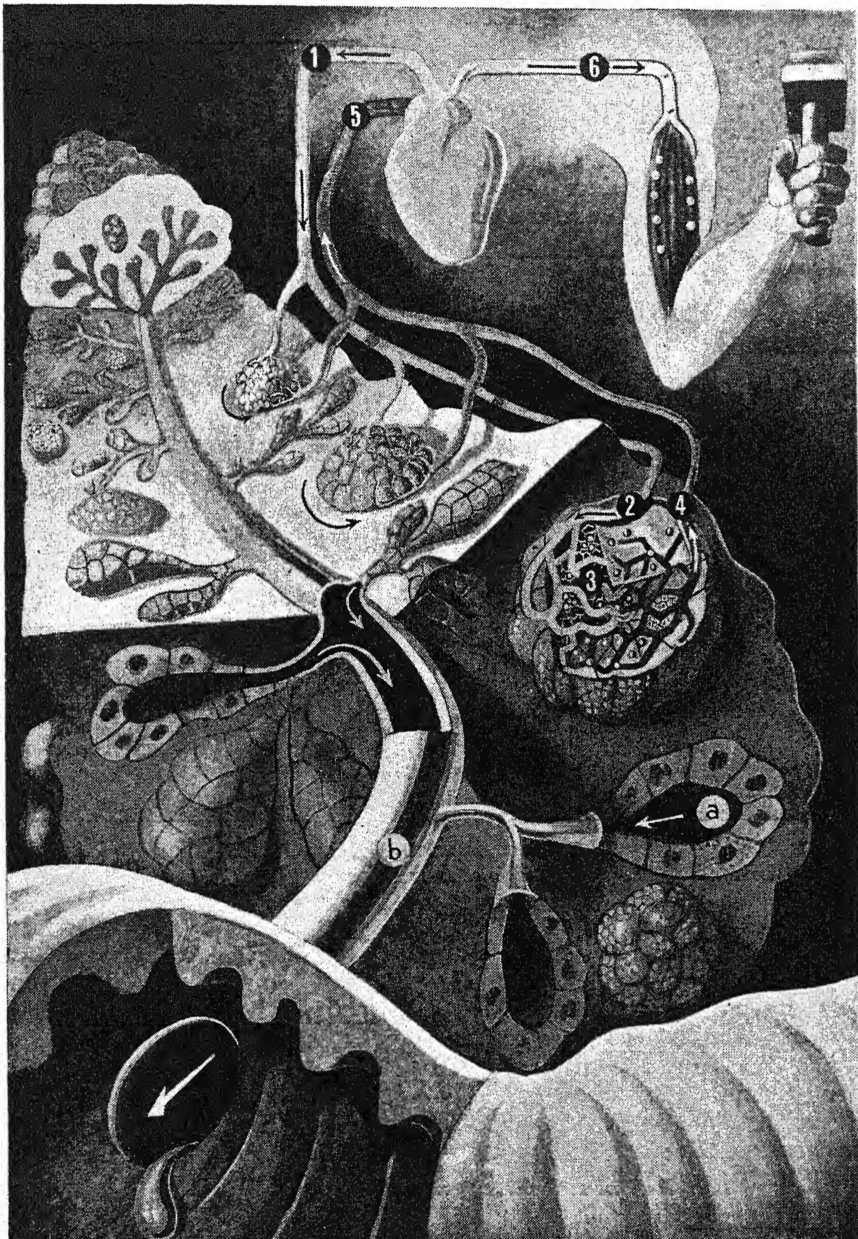


FIG. 193. *The interior of the pancreas. The "island" cells (3) occur in groups. Nourished by blood vessels (1, 2), they pour their hormone secretion (insulin) directly into the blood-stream (4, 5). Transported by the blood (6), insulin stimulates distant organs, such as the muscles. (See also Chapter XXIV.)*

diet is prescribed for those affected with gall-bladder disease.

The Pancreas and Its Four Ferments. To all external appearances the pancreas is a very modest part of the digestive apparatus. It is small, weighing only one twentieth as much as the liver, inconspicuous, and grey, and lies hidden in the horseshoe-shaped loop of the duodenum, between the posterior wall of the stomach and the spinal column. When sectioned it exhibits nothing remarkable, but resembles the salivary glands very closely. The pancreas secretes less than any other digestive gland, only one fifth as much as the considerably smaller salivary glands—and yet it surpasses all the other digestive glands in importance and activity [Fig. 192 (I)].

Pancreatic juice contains no less than three ferments, and they are the most active substances in the entire digestive canal:

1. A starch-splitting ferment, amylopsin, or pancreatic amylase, which like the ferment of the salivary glands splits starch (amylum) into glycogen, dextrin, and finally into malt sugar [Fig. 194 (a), (b)].

2. The protein ferment trypsin splits protein (c) into albumoses (d) and peptones (e), and these into their ultimate constituents, the amino acids (f).

3. The fat ferment lipase splits the fat, which has been emulsified by the bile, into fatty acids and glycerin [Fig. 172].

Like the other digestive glands the pancreas is activated by the brain,

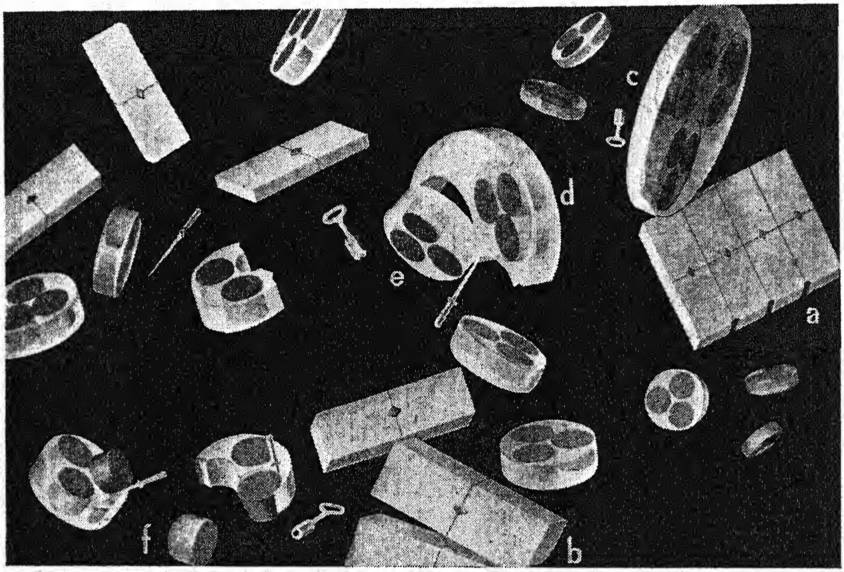


FIG. 194. *Digestion by the pancreatic juice. The more complex carbohydrates (a) are broken down by the pancreatic juice to malt sugar (b); while the proteins (c) are converted into albumoses (d), peptones (e) and the ultimate elements of protein, the amino acids (f). In addition, the pancreatic juice also breaks down fats to fatty acids and glycerin, although this is not shown above. (See also Figs. 175, 185 and 202.)*

and in the dog it has even been possible to discover the centre by which the pancreas is stimulated. In addition, like the liver and the gall-bladder, it is controlled by various nerve apparatuses in the intestinal canal. If hydrochloric acid from the stomach enters the intestine, it stimulates the intestinal cells to secrete a substance which passes into the blood and reaches the pancreas, where it reports: "The stomach has sent acid food into the intestine. Prepare your secretion!" Two minutes after the arrival of the first acid food in the intestine the pancreatic juice begins to flow from the gland.

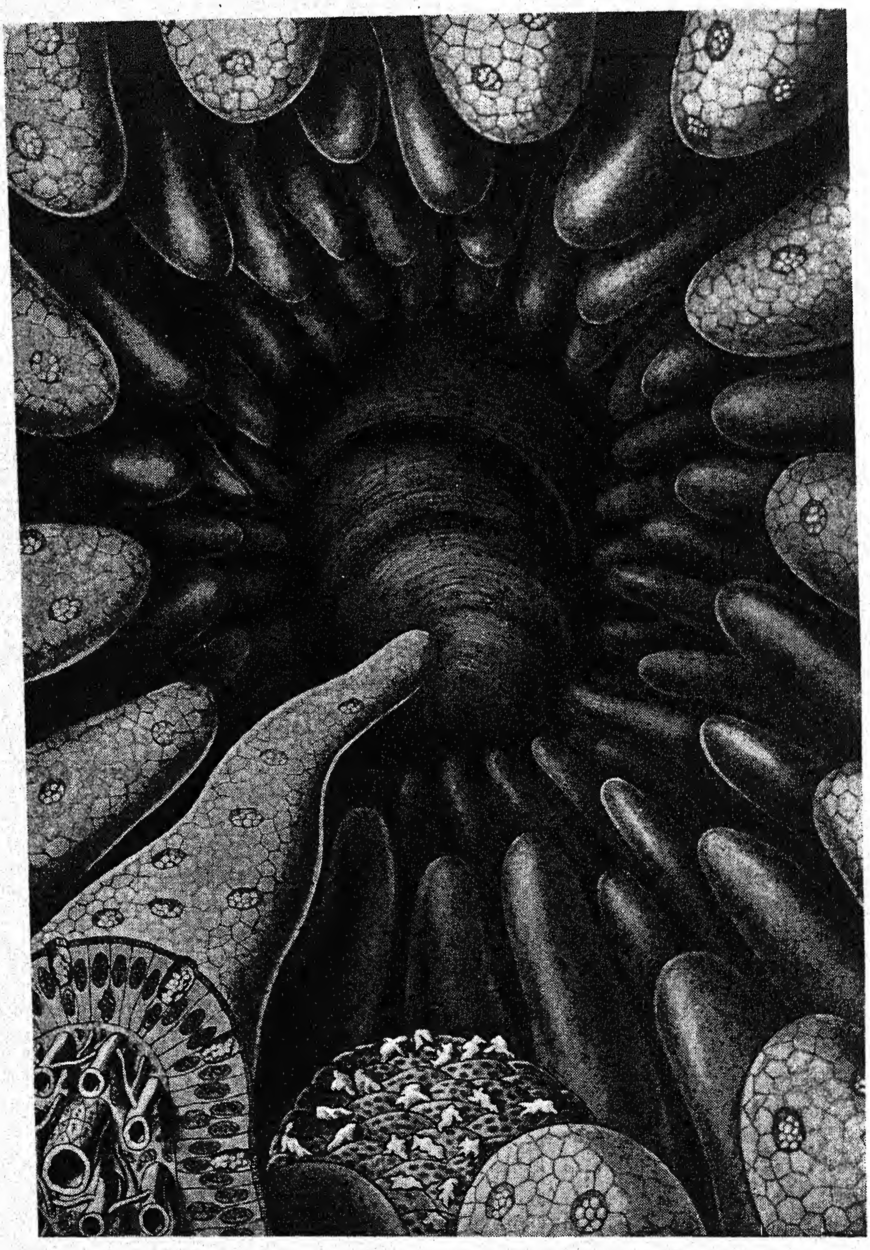
Self-Protecting Cells

Like the gastric juice, the pancreatic juice is also secreted in an inactive form, and first converted into an active form by a special substance, enterokinase, secreted by the mucous membrane of the small intestine. In this way the cells of the pancreas protect themselves against the digestive action of their own powerful secretion.

The Islands of the Pancreas. Groups of cells lie scattered in the tissue of the gland. They are so isolated that they are called islands [Fig. 193 (3)]. These cells are not connected with the duct of the gland, and consequently their secretion is unable to flow into the intestine. It passes into the blood vessels that surround the islands and is carried away by the blood-stream (4).

The Ductless Glands

The secretion of these groups of island cells in the pancreas is known as insulin. It is one of many glandular products that are not secreted by means of ducts to the surface of the glands but pass into the blood, and are therefore known as endocrine or internal secretions. These substances are also known as hormones, from the Greek word *hormao,* "I urge," because they act as chemical messengers to stimulate distant organs. Insulin is carried by the blood to the muscles and the liver, enabling these organs to utilize the sugar in the blood and to store it in the form of glycogen. Diabetes is due to a lack of insulin. The diabetic patient is unable to burn up sufficient sugar in his muscles or store it in his liver in the form of glycogen, and consequently the sugar content of his blood rises to an abnormal degree. This condition is relieved by administering insulin obtained from the pancreas of sheep and other animals.



A VIEW INTO THE INTESTINAL CANAL

FIG. 195. *The internal wall of the intestine is furnished with about five million villi, each of which has three thousand cells, some of these being absorptive, while others produce mucus. Phagocytes (Bottom Centre) wander out of the lymph nodes and assist in transporting food particles along the intestine.*

CHAPTER XXIII

The Intestine

THE LENGTH OF THE INTESTINE. THE INTESTINAL MUCOUS MEMBRANE. INTESTINAL MUSCULATURE. INTESTINAL FOLDS. THE CÆCUM. DIGESTION IN THE INTESTINE. INTESTINAL VILLI. CELLULOSE. PUTREFACTION. THE APPENDIX. INTESTINAL GASES. CONSTIPATION.

THE part of the digestive apparatus beneath the stomach is known as the intestine [Fig. 169 (b-h); Fig. 196]. It consists of two sections, the small [Fig. 196 (c) (1-6)] and the large intestine (6-8). Below the point where the small intestine enters the large intestine the latter forms a blind sac known as the cæcum (6).

The length of the large intestine in different animals depends entirely on the nature of their food. In carnivores the large intestine is shorter because they have less digestive work to perform, since the herbivores on which they feed have already accomplished the more difficult part of digestion—namely, the transformation of plant substances into animal substances. Man occupies a somewhat intermediate position between carnivora and herbivora.

Those peoples that subsist on vegetables are supposed to have longer intestines than members of meat-eating groups. In nature there are no laws, only rules and exceptions to the rules. The rule concerning the relation between nutrition and the length of the intestine is not valid for aquatic animals. The dolphin has the relatively longest intestine of all animals (50 times the length of its body); the seal is next (28 times the length of its body). Among domestic animals sheep and pigs have the longest intestines, 27 times the length of the animal in sheep, and 14 times in pigs, while in dogs and cats the intestine is 4 to 6 times the length of the animal. The human intestine is 28 feet long. However, all these measurements are valid only after death, when the tonus of the muscle fibres is gone. During life the human intestine is only 10 feet long.

The Parts of the Intestine. In Figure 169 we can trace the tortuous path of the intestine. After leaving the stomach food passes into the first convoluted section of the small intestine, known as the duodenum (b) because it is twelve finger-breadths long (from the Latin *duodeni,* meaning "twelve at once"). Here the ducts of the liver and the pancreas empty into the intestine [Fig. 192 (a), (b)]. Then the food traverses many loops of small intestine [Fig. 169 (c, d, e)] into the right, lower region of the abdomen (f). Where the small intestine enters the large intestine, there are two flaps of mucous membrane that function as a valve. On the other side of this valve is the large intestine. In contrast to the numerous coils of the small intestine, which are not arranged in any particular order, the large intestine is an organ with a definite form and

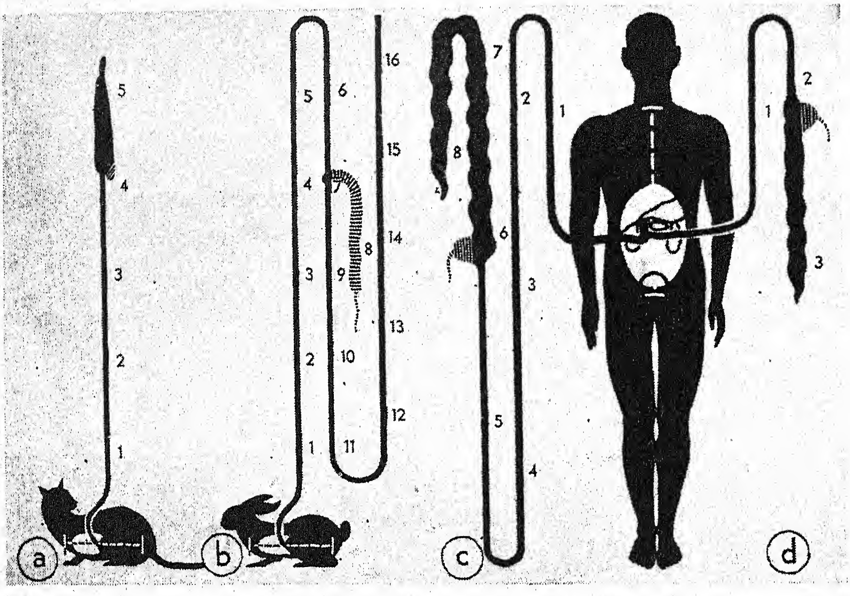


FIG. 196. *Carnivores (a) have a short, and herbivores (b) a long, intestine—roughly five and sixteen times as long as the trunk respectively. The dead human intestine (c) is eight times the trunk-length, although during life muscle tonus contracts it to about ten feet (d). The narrow tract is the small intestine, the broad part the large intestine; the striped portion is the cæcum. The numbers indicate trunk-lengths.*

location. It begins with the cæcum, located in the right, inferior abdominal region (g), ascends perpendicularly to the liver (h), then passes horizontally in front of the lower border of the stomach leftwards to the spleen. At this point it turns downward and descends to the pelvis, where it describes an S-shaped curve and passes into the rectum, which terminates at the anus: Figures 198 and 199 (c, d, e, f, g) show the small intestine and the large intestine respectively.

The undulating, fringe-like tissue in Fig. 199 is the edge of the mesentery, which has been severed vertically, while much of the small intestine has been removed. The mesentery is a fold of the peritoneum by which the intestine is attached to the posterior wall of the abdomen. The severed ends of the small intestine are shown at (a) and (b).

The apparently confused mesentery becomes comprehensible if one traces it from (a) along the convolutions of the fringe to (b), bearing in mind that the small intestine was suspended from the fringe. At (c) is the cæcum, the first part of the large intestine; (d) is the ascending colon; (e) the transverse colon; (f) the descending colon and the sigmoid (S-shaped) flexure; (g) is the rectum.

Mucous Membrane. Although it is barely, if at all, thicker than the paper of this page, the intestinal wall possesses a most ingenious structure [Fig. 197]. No fewer than nine layers (a-i) are superimposed! The uppermost, inner layer consists of high columnar cells. The exposed ends of these cells exhibit a bright striated

edge which is probably of great significance for the absorption of the digested food. Among these cells are others, shaped like goblets and filled with a special protoplasmatic product called mucin. In the upper left corner a goblet cell is shown in the act of pouring out its contents; in the opposite corner an empty goblet cell is seen in the resting stage. Goblet cells are the smallest glands in the body; they are unicellular glands. Membranes containing such goblet cells are covered with a moist mucous coat, and are known as mucous membranes. The oral cavity, the alimentary canal, the conjunctival sac of the eye, the respiratory passages, and the urogenital passages are lined with mucous membranes.

The Intestinal Musculature. The greater part of the intestinal wall consists of muscle fibres, arranged in two layers, an inner circular and an outer longitudinal one [Fig. 197 (e), (f)]. With the changing tonus of these muscles the intestinal tube becomes narrower or wider, and the alternate contraction and relaxation of the muscles produces the peristaltic movements of the intestine. Between the muscle layers pass nerves and blood vessels arranged in extremely complex systems. The movements of the intestine are excited and regulated by the mass of digested food which fills the intestinal tube. The food entering the small intestine is subjected to two kinds of movements. The purpose of these movements is to mix the food thoroughly with the intestinal secretions and to move it along the intestine. The small intestine consists of innumerable loops [Fig. 198]. At any given time each loop contains a certain quantity of food. This food is mixed by means of a series of movements described as rhythmic segmentation. At intervals of about an inch the circular muscle fibres contract simultaneously, thus segmenting the food contained in the intestine. These constrictions soon vanish and are followed by new ones located halfway between the first. Thus the food is again segmented but in another position. These constrictions, in turn, are followed by another group in the

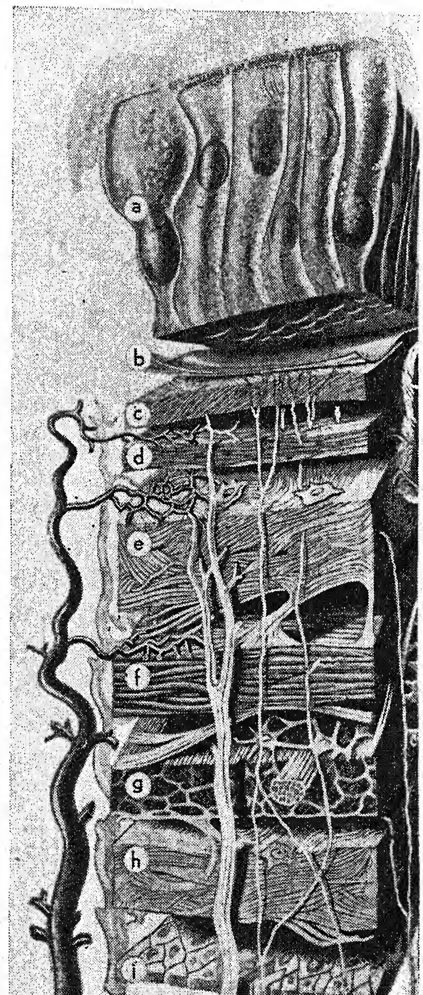


FIG. 197. *Section of the intestinal wall.*

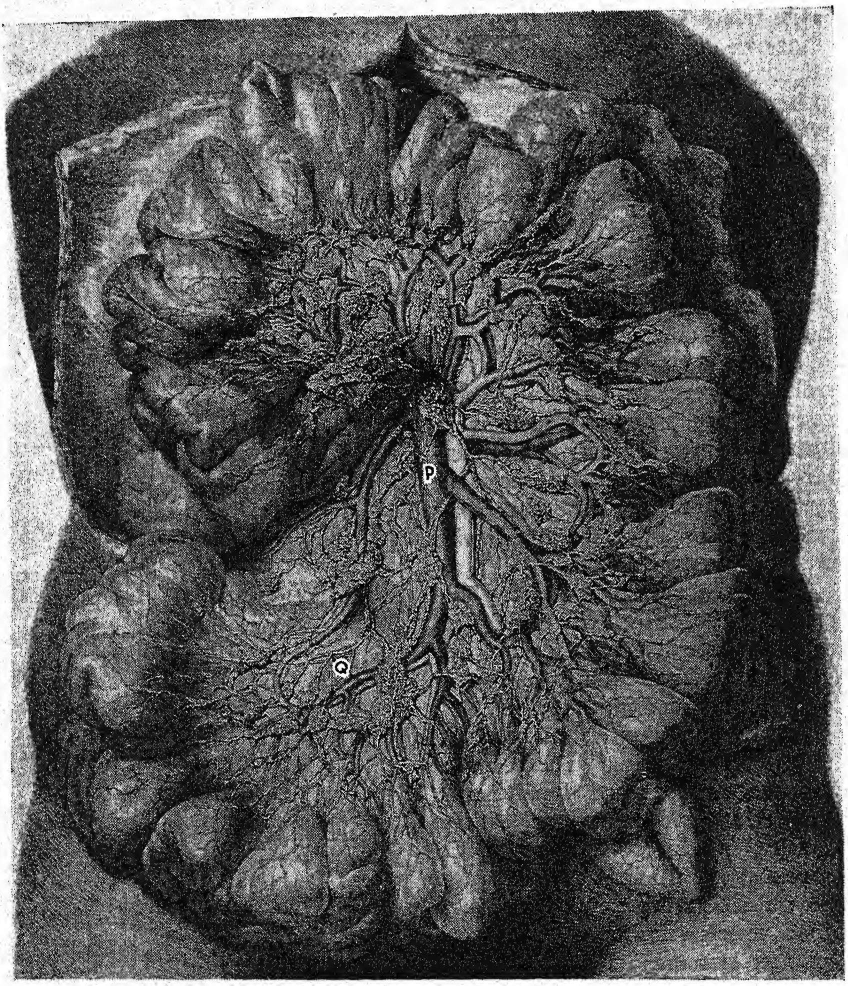


FIG. 198. *The small intestine with its system of blood vessels and lymph vessels. The blood vessels convey protein and sugar through the portal vein (P–Q) to the liver. The lymph vessels convey fat from the intestine to the blood near the heart.*

same position as the first one. These stationary waves recur ten to twenty times a minute, and the entire mixing process lasts thirty to sixty minutes. During this period digestion takes place. The food mass contained in the intestine is churned and thoroughly mixed with the intestinal secretions. After the food has been thoroughly churned for about thirty minutes, the constrictions die away and a peristaltic wave develops which carries the mass into the next loop, where the same process is repeated. In this manner the food is digested and propelled through the small intestine.

The Intestinal Folds. In order to be able to absorb the products of digestion better, the intestinal wall

in the course of its evolution has developed folds. The amphioxus, the lowest of present-day vertebrates, has a smooth intestine. In primitive lamprey eels the intestine acquires a longitudinal fold; in lower cartilaginous fishes this fold takes a spiral course; and in the higher vertebrates the spirals are so close together that they are almost transverse to the longitudinal axis of the intestinal tube [Fig. 200]. The food is delayed by these folds, since it must collect in the hollows between them and pass over each individual fold like a horse over the hurdles of a racecourse. Since the folds are not stiff, but mobile, they function as spoons that stir and mix the food.

The Cæcum. The coils of the small intestine wind back and forth, but, like the turns of a descending mountain road, they carry the food deeper and deeper. The end of the small

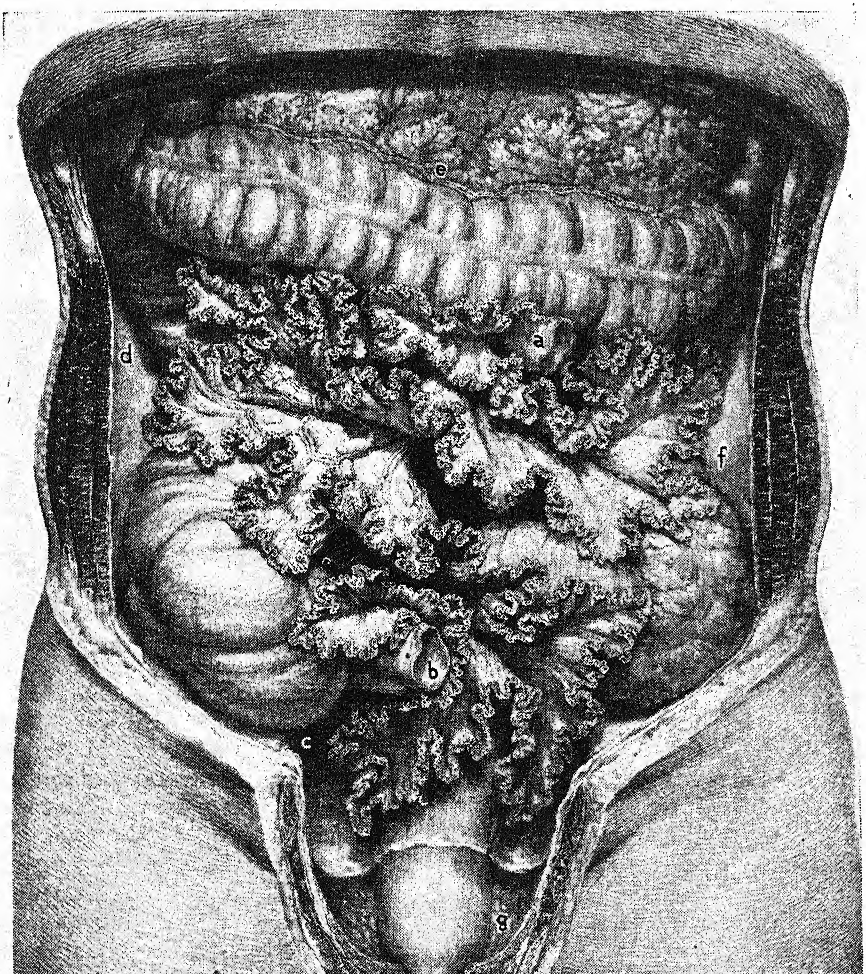


FIG. 199. *The large intestine, with the mesentery, after removal of the small intestine.*

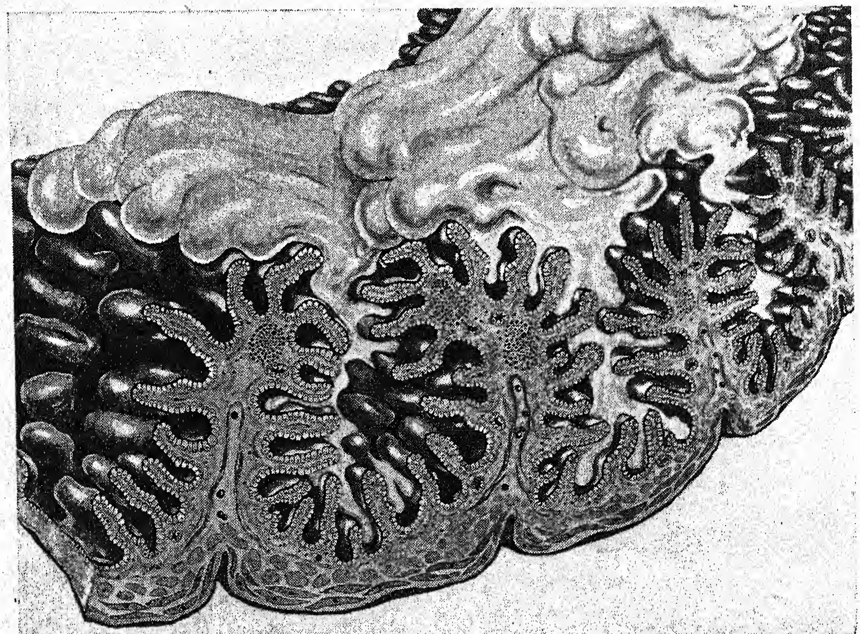


FIG. 200. *The folds of the intestine. In order to increase its digestive and absorptive surface and to ensure as close a contact as possible between the food and the digestive juice, the intestinal wall has developed transverse folds. Each fold bears smaller processes called villi, which resemble minute tentacles.*

intestine in the right lower quadrant of the abdomen is likewise its deepest point. Here the food must pass a valve, and now it enters the widest portion of the intestinal canal, the cæcum. The cæcum is the closed end of the large intestine below the point of communication with the small intestine, and is about the size of a fist. The lower fishes have no cæcum. In bony fishes, however, the intestine has developed accessory spaces, analogous to the cæcum—in some cases as many as two hundred! In land animals these accessory spaces have disappeared and mammals have only the cæcum. Herbivorous animals that devour large quantities of food which is hard to digest have a large cæcum; carnivores have a small cæcum or none at all. Man is intermediate between these two groups, but is closer to the carnivora.

When it enters the large intestine the digested food is a semi-liquid. In the cæcum and the ascending and transverse portions of the large intestine this material is thickened by the absorption of water from it, until it is transformed into semi-solid fæcal matter. In order to prevent their contents from passing on too rapidly, these portions of the large intestine carry out anti-peristaltic movements. These movements consist of peristaltic waves that start in the transverse colon and sweep backward towards the valve separating the large from the small intestine. These movements cause a thorough churning up of the contents and produce a close contact with the in-

testinal wall, resulting in the absorption of water. The drier, semi-solid mass collects in the transverse portion of the large intestine. True peristaltic waves then carry these hard masses into the rectum.

A Natural Hydraulic Press. The ascending portion of the large intestine is the only section of the intestinal tract in which the food must rise perpendicularly against the force of gravity for some distance. For this purpose a special force is needed. The force employed is hydraulic pressure. The cæcum works on the principle of a hydraulic press. According to the fundamental law of hydraulics, the pressure exerted on a fluid or semi-fluid mass is transmitted equally in all directions. If pressure is exerted through a narrow water-filled tube with a cross section of one square centimetre on a water-filled chamber with a cross section of one square metre, each square centimetre of the chamber exerts a pressure equal to that exerted by the water in the small tube. The pressure effect increases at the surface of the water, in this case ten thousand times. The orifice by which the small intestine communicates with the large intestine is narrow. At a result the pressure in the former is increased. This increased pressure acts as a hydraulic force on the contents of the cæcum and raises it without any effort in the ascending section of the large intestine [Fig. 201].

Digestion in the Intestine. During its passage through the intestinal canal the food is digested. The wall of the small intestine contains not only muscle fibres but approximately twenty million small glands that secrete no less than five to ten quarts of juice into the intestine [Fig. 203 (b)]. This fluid soaks and softens the food to such an extent that, with the exception of its absolutely insoluble constituents, such as hard shells, small fruit seeds, and indigestible fibres, it is partly liquefied and passes from the small to the large intestine in this semi-liquid state. Here this food is again thickened by the withdrawal of water and changed into fæces. Like the pancreatic secretion the intestinal juice also contains three ferments [Figs. 172, 202]: a

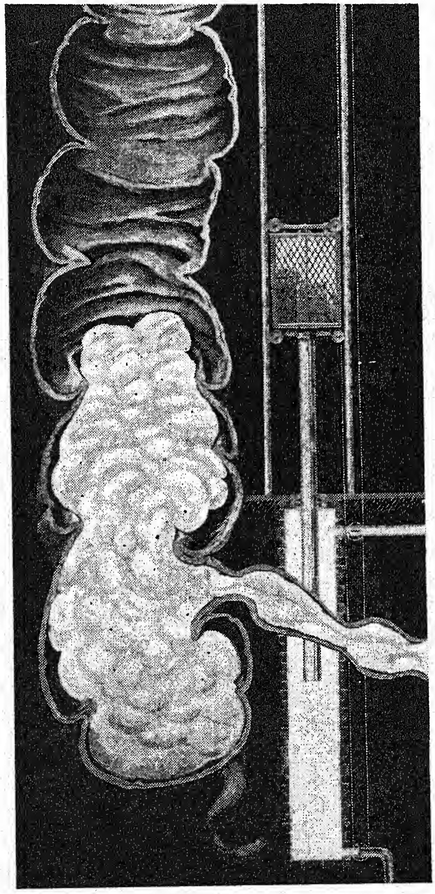


FIG. 201. *The small intestine and cæcum form a hydraulic press, which helps to propel the contents of the large intestine upwards against the force of gravity.*

carbohydrate ferment, which splits all higher sugars and starches to grape sugar (a), a protein ferment that breaks down all proteins into their constituent amino acids (b), and a fat ferment that splits fat into glycerin and fatty acids

The Intestinal Villi. In order to be able to absorb the digested food as well as the large quantities of secreted digestive fluids, the intestinal wall has enlarged its surface by developing not only larger folds but also minute processes known as villi. When examined with a lens the mucous membrane is seen to be covered with closely packed processes resembling the pile of velvet. Each villus is $\frac{1}{50}$ to $\frac{1}{35}$ of an inch long [Fig. 195]. In their structure and actions the villi resemble the tentacles with which lower sea animals, such as corals and sea-anemones, capture and suck out their prey. In Figure 203 the life of the intestinal villi is represented in extremely simplified form. (A), (B), and (C) are three intestinal villi in different phases of their activity. (A) is an empty villus filling itself with food, (B) is a filled villus, and (C) is a villus that has evacuated its contents.

Chemistry of the Bowel

At the upper left is a food particle that has passed into the small intestine in a half-digested condition. By pressure on the villi beneath it (e) the gland (b) at the bottom is notified of the arrival of the particle, whereupon it pours a stream of digestive juice (c) over the food. In addition to the mechanical stimulus exerted by the intestinal contents, the flow of intestinal juice is also provoked by chemical stimulation. At the same time wander cells creep out of the lymph node (d) to gnaw at the food and to carry away its insoluble parts. As a result of the digestive action of the glandular secretion meat is converted into meat water (amino acids), starch into sugar water (grape sugar), and fat into glycerin and soap. A villus is lined with 3,000 cells, and each cell has a bright striated border by means of which it performs its absorptive function [Fig. 197].

"Milk Pumps"

In the interior of the villus there are two sets of pipes, the blood- and the lymph-vessels. The blood-vessels [Fig. 203 (g)] are located externally and absorb both amino acids and sugar. These two classes of substances pass by way of the path (1, 2, 3) into the blood-stream. The lymph-vessels end as narrow bags (f). These bags suck themselves full of glycerin and soap (I), from which they form human fat, so that the nutritive fluid is transformed into a kind of milk. When the villus has become filled with milk (II), it contracts and pushes the milk into the lymph-vessels (III). Intestinal villi are "milk pumps."

Cellulose. All easily digestible substances are absorbed in the small intestine. The remaining materials pass the valve between the small and the large intestines and enter the cæcum. Here a new section of the alimentary canal with new digestive methods begins. Until now the food has been digested by the glandular secretions, acids, and ferments. The remainder of the food, which has resisted digestion until now and passes into the cæcum, can no longer be taken care of by means of animal secretions. The animal body is able to split starch into sugars, protein into amino acids, and emulsified fat into glycerin and soap However, a

vegetable diet contains carbohydrates that are harder than starch and cannot be attacked by the ferments of the animal body. In the human diet the most common of these carbohydrates is cellulose. Cellulose is a substance manufactured by plants from sugar and starch in order to protect their soft interiors beans, the brown skins of wheat grains are all cellulose capsules. Cellulose cannot be digested by the animal body, so the capsules of nuts, wheat, etc., must be removed before these plant products are eaten. The internal framework of oranges, apples, potatoes, asparagus, etc., also consists of more tender forms of

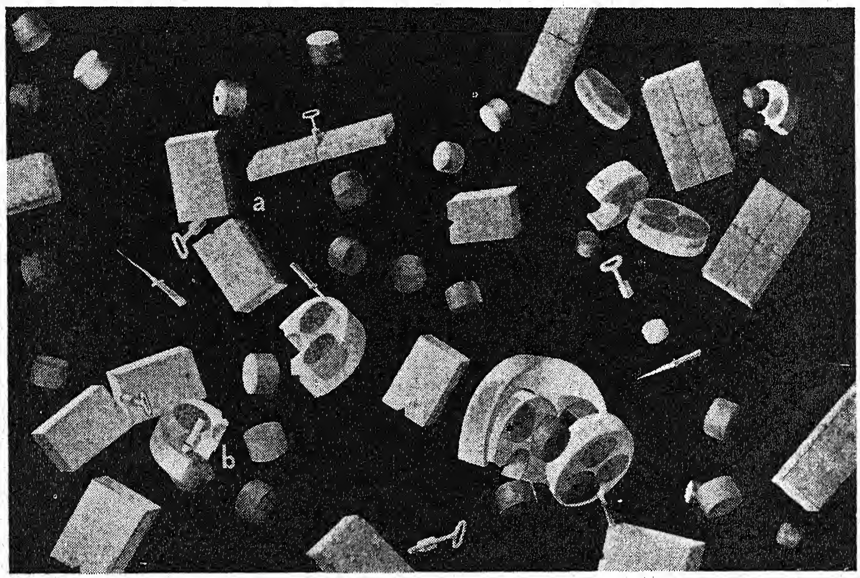


FIG. 202. *Digestion in the small intestine. The enzymes produced by the glands of the small intestine break down the food molecules to their simplest components. Carbohydrates are converted to grape sugar (a), proteins to amino acids (b). The break-down of fats is not shown above. (See also Figs. 175, 185 and 194.)*

from being destroyed by water, wind, light, and above all by insects. The bark of a tree is a covering of cellulose, by means of which the tree prevents any contact between its vascular system and the outer environment. A nutshell is a small cellulose chest in which the plant packs its embryo so that it can pass the winter in safety. Every plant embryo lies in such a cellulose cradle. The skin of an apple or a turnip or the peel of an orange, the pods of peas and cellulose. Thus a vegetable diet brings cellulose into the intestine; the coarser the diet, the greater is the quantity of cellulose. A fine diet containing wheaten flour, noodles, macaroni, farina, white bread, and rice is a diet that contains little cellulose and is consequently completely digested in the small intestine. A coarse diet consisting of the darker kinds of flour, black bread, cabbage, turnips, cucumbers, pumpkin, berries, and mushrooms is a diet contain-

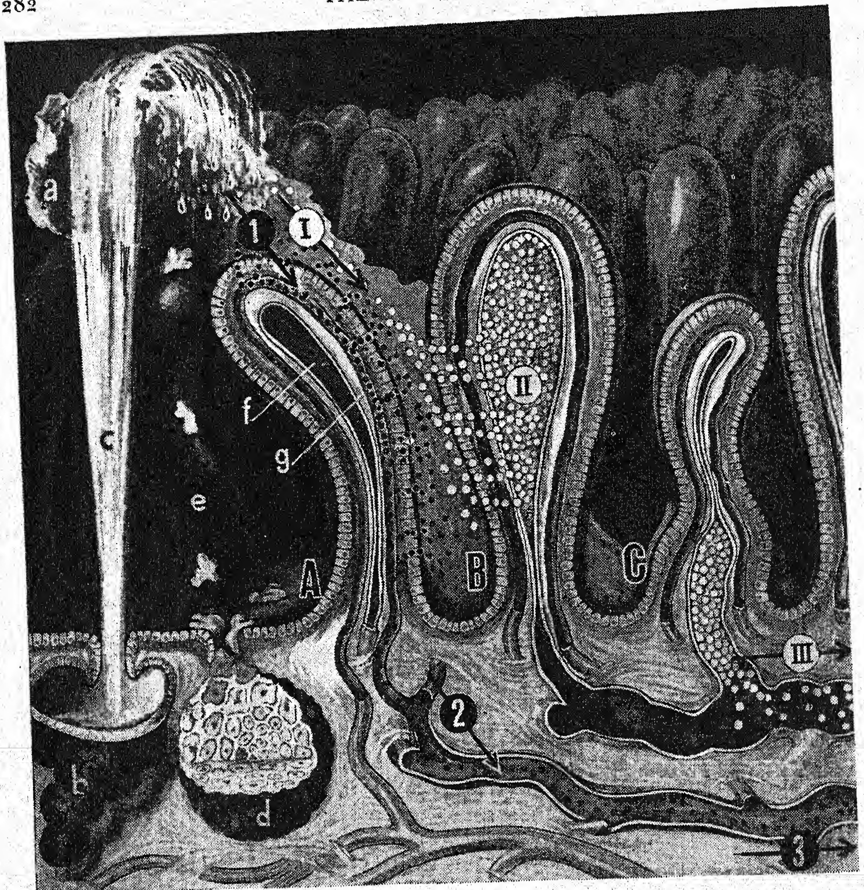


FIG. 203. *The life of the intestine, showing villi in various stages of activity.*

ing large quantities of cellulose. The nutritious substances of these plants are for the most part enclosed in cellulose coverings. Potatoes and oatmeal are approximately intermediate between coarse and fine foods. The latter are digested in the small intestine; the former enter the cæcum in considerable quantities.

Putrefaction in the Large Intestine. The animal body is powerless against cellulose, but many bacteria live by breaking down cellulose molecules. Approximately seventy species of these bacteria live in the large intestine—countless billions of them! Man excretes about 100 thousand million bacteria daily by way of the intestine. These bacilli live exclusively in the large intestine. In contrast to the ferment digestion in the mouth, stomach, and small intestine, food is subjected to bacillary digestion in the large intestine. This type of digestion is known as putrefaction. The nutritive material obtained by the digestion of cellulose is slight and insignificant for man. Despite the bacilli of the large intestine, man cannot live on wood shavings and

potato peelings. However, the swollen and half-digested skins still contain valuable nutritive materials that are liberated by intestinal putrefaction. The most valuable protein of rye is found in the cellulose husks contained in black bread; the most nutritious substances in a potato are found under the skin; and the same is true of apples and berries. For this reason it is best not to feed children exclusively on peeled fruit, or white bread, farina, and noodles, but to add coarser foods to their diet.

A Slow Process

In contrast with digestion by means of ferments, putrefaction is a slow process. As a result the food remnants remain much longer in the large than in the small intestine. In order to mix the food well with the bacilli, and to give them time to initiate putrefaction, the cæcum is interposed as a large sac between the small intestine and the rest of the large intestine. For this reason, too, the large intestine carries out its antiperistaltic movements, by means of which the food mass is prevented from rising rapidly and is repeatedly mixed and churned [Fig. 201].

The Appendix. The vermiform appendix, a narrow tube projecting from the cæcum, is not really a digestive organ. It is abundantly equipped with lymphoid nodules. Frequently the appendix becomes inflamed, producing the condition known as appendicitis and requiring surgical intervention.

Intestinal Gases. During putrefaction gases are produced. When dough ferments, carbon dioxide bubbles are formed. This gas produces the pores in bread and makes the compact dough light and digestible. Carbon dioxide arises in a similar manner in fermenting wine. In the course of intestinal putrefaction carbon dioxide and methane are formed from fermented sugar, ammonia is split off from the amino acids, and phenol, cresol, indol, skatol, and hydrogen sulphide (sulphuretted hydrogen) arise from the complex proteins. The foul-smelling gas produced after eating legumes rich in sulphur, eggs, onions, and chives is hydrogen sulphide.

Fæces. In the large intestine the food is once more subjected to a process of elimination. Whatever nutritious elements remain are absorbed, water is removed from the fæces to thicken them, and in addition the large intestine excretes a number of waste products formed in the body. As the terminal section of the alimentary canal the large intestine is not only an organ for the absorption of nutritive substances but also an important excretory organ.

Excretion

Solid, fluid, gaseous are the three states of matter, and the body has an excretory organ for each form. The lungs excrete gases, the kidneys water-soluble salts, and the large intestine insoluble metabolic compounds. Independently of the ingested food, the large intestine excretes daily twenty grams of substance, consisting in part of thickened indigestible food remnants and digestive juices, in part of iron and calcium compounds excreted from the blood. If an animal is starved it nevertheless produces slight quantities of fæces. This fæcal material has a black, tarry character. When a child leaves its mother's womb it has eaten nothing but the water contained in the uterus, and hairs floating around in this water. Yet its

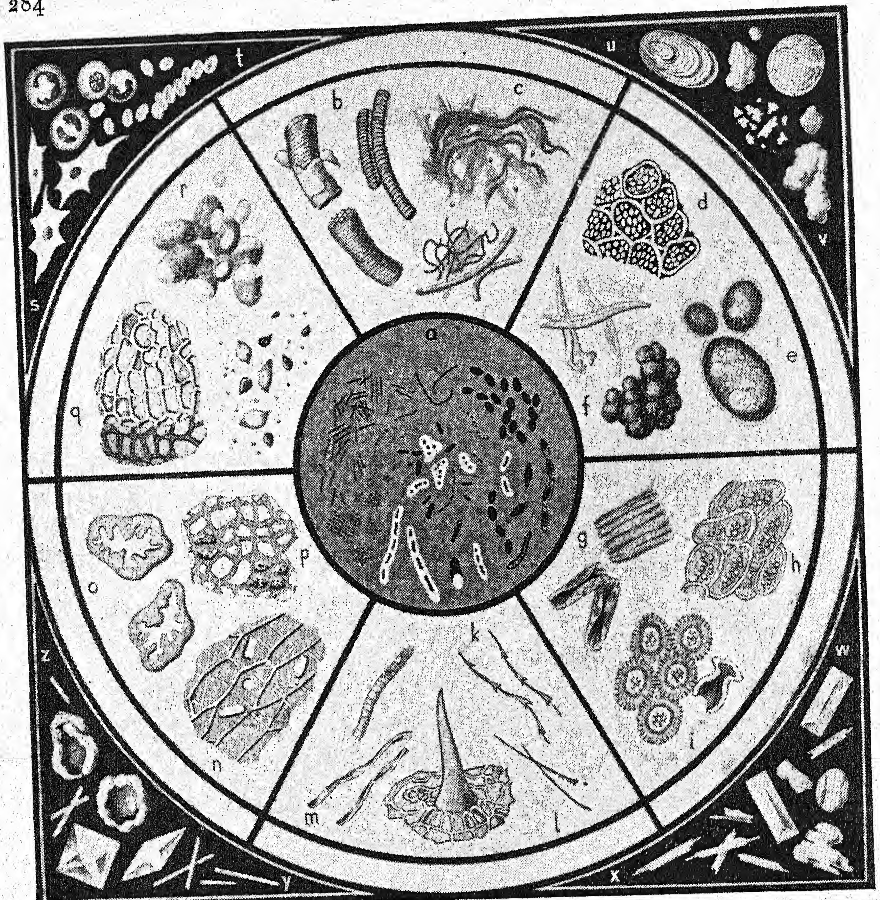


FIG. 204. *In human fæces the microscope reveals: (a) seventy-five different kinds of bacteria, (b) meat fibres, (c) connective-tissue fibres, (d) bread remnants, (e) beer yeast, (f) cocoa particles, (g) rice husks, (h) bean particles, (i) pea skins, (k) feathers, (l) bones, (m) plant stems, (n) onion skins, (o) pear particles, (p) apple skins, (q) nutshells, (r) fruit pips, (s) connective-tissue cells, (t) blood corpuscles, (u) starch granules, (v) fat globules, (w) phosphorus, (x) iron, (y) magnesium, (z) calcium compounds of fatty acids. Stool investigation is a valuable aid in diagnosis.*

large intestine contains a dark brownish-green fæcal mass, known as meconium, which the child evacuates after it is born.

Besides water, normal human fæces contain chiefly bacilli—man excretes several billion bacilli daily. In addition fæces consist of undigested meat and vegetable fibres; skins of fruit and vegetables; coffee, tea, or cocoa particles; and, finally, constituents excreted by the large intestine such as calcium, iron, phosphorus, magnesium, blood and connective-tissue cells, crystals of fatty acids, and the like. Figure 204 shows these remnants of the digestive process arranged in a series (a) to (z). Stool

investigation is one of the diagnostic methods employed by the doctor. The quantity of fat contained in the fæces reveals information regarding the digestive power of the pancreas; the presence or absence of bile pigments is indicative of the functional state of the liver; the presence of blood may reveal bleeding somewhere in the intestinal tract; and pus cells show concealed suppuration.

Constipation. The inadequate elimination of fæces is known as constipation. The question of how many bowel movements a normal person should have in one day cannot be answered. On the average an individual has one evacuation in twenty-four hours. There are people, however, who go to stool several times a day and are still normal and healthy. The concept of constipation cannot be understood simply on the basis of the number of stools, or of the time elapsing between evacuations. A person is constipated who carries thickened fæcal material for an unnecessary length of time in his intestine because he either goes to stool too infrequently or has an inadequate evacuation.

Incomplete Elimination

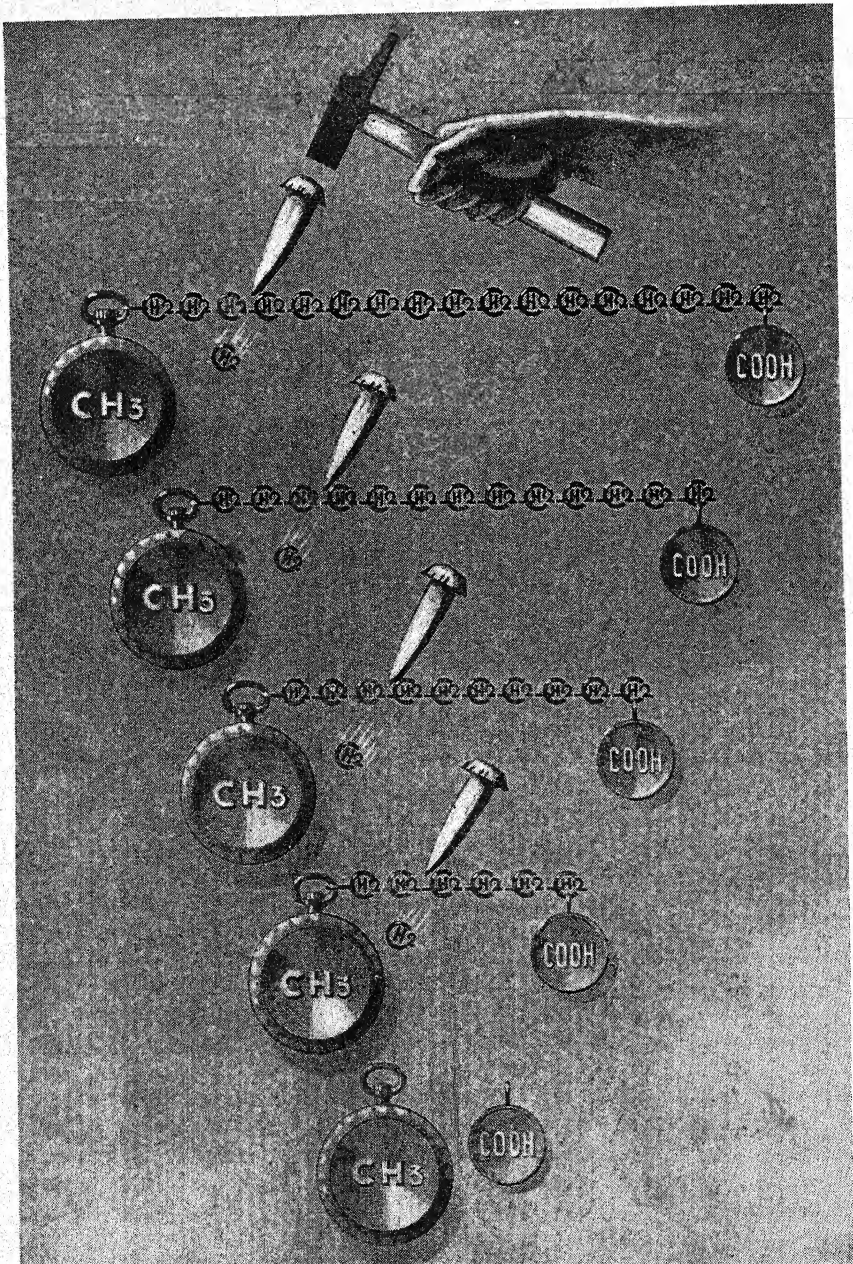
Normally, about four fifths of the fæcal material to be evacuated should be present in the rectum when the individual goes to stool, and should be completely evacuated so that after a bowel movement only one fifth of the fæcal mass remains behind in the upper sections of the intestine. Constipation is present if considerable quantities of fæces remain in the large intestine after an evacuation, no matter how often the individual goes to stool or how much fæces he evacuates. An individual can have a bowel movement daily and yet be constipated, because despite a normal evacuation an equally large or often still larger quantity of fæces remains in the upper sections of the large intestine.

Training the Intestine

The existence of constipation can be recognized more easily from the character of the evacuated fæces than from the quantity or frequency of the stools. A normal stool evacuated at the right time should have the form of a column. If the stool is too fluid, so that it flows apart, a premature evacuation or diarrhœa is present; if it is so hard that, instead of a column of fæces, small pieces or ball-shaped fragments, the size of plums or cherries, are evacuated, then defecation is delayed.

A healthy intestine should be so regulated that the evacuating mechanism of the rectum will be activated when the fæcal column has attained a certain degree of hardness. When a sufficiently hard and large column of fæces has collected in the descending branch of the large intestine, producing a certain degree of distension, the fæces are passed into the rectum. The entry of fæces into the rectum gives rise to a feeling of fullness and acts as a call to defecation.

The Therapy of Constipation. The best remedy against constipation is the training of the intestine to acquire regular habits. The act of defecation is semi-automatic; one can learn to control it both positively and negatively. During the first two years of its life a child must be trained to evacuate its intestine every morning. This routine must be carried out quite strictly. Once the intestine has established a regular habit, it continues to function automatically throughout life



METABOLISM OF FATS IN THE BODY

FIG. 205. *Under the blows of an enzyme hammer, the oxygen chisel knocks a* CH_2 *group from each fatty acid in turn, like severing the links of a watch-chain.*

VII: METABOLISM

CHAPTER XXIV

Fuel Becomes Energy

MAN AND MACHINE. WATER METABOLISM. THE BLOOD REMAINS UNCHANGED. THE IMBIBED FLUID. THE WATER CENTRE. INTRAVENOUS INFUSION. COMBUSTION AND OXIDATION. FAT METABOLISM. SUGAR METABOLISM. INSULIN. PROTEIN METABOLISM.

MAN and machine exhibit far-reaching similarities [Fig. 207]. Both derive their energy from the combustion of carbon which they obtain from plants. Man, the weaker machine, utilizes fresh plants for fuel, while the locomotive, a stronger machine, uses fossilized plants in the form of coal. They inhale oxygen, combine it with carbon by means of combustion (1), and exhale the carbon dioxide produced during this process (6). They employ water, which circulates through the blood- and lymph-vessels of the body, and through the pipes of the machine, as a heat conductor. An incombustible remnant is left over as ashes or fæces. Both transform the energy thus obtained into the motion of levers rotating in joints (4).

The various changes which the substances undergo within the body-machine during these processes is known as metabolism.

Water Metabolism. In the course of a day man ingests approximately two quarts of water as fluids and one quart in so-called solid foods such as fruit, vegetables, bread, and meat, which are really not dry since they are 30 to 90 per cent water [Figs. 222 and 223]. Besides these three quarts that enter the body from outside in the course of a day, about ten quarts of water pass back and forth within the body between the various organ systems. In order to convince ourselves, let us stop reading for a moment, suck some saliva from the salivary glands, and swallow it. What have we done? We have sucked a small quantity of water from the glands; in order to replace it an equal quantity of water passes out of the blood vessels into the salivary glands during the next few moments. This transfer of water from the blood to the mouth is repeated as often as we swallow. The swallowed water returns from the stomach and intestine to the blood, and thus ten quarts circulate daily between the blood and the organs.

The Blood Remains Unchanged. The quantity of blood in the vessels is about five quarts. Two of them comprise the solid and dissolved constituents such as cells, salts, the clotting substance, fibrin, while the water in which these elements are contained makes up the other three

quarts. The salt content of the blood corresponds to a concentration of one per cent. Despite the continuous active passage of water, the water as well as the salt content of the blood remains unchanged. No matter whether an individual is "dried up" after a long hike in the summer heat, or whether he returns home after a convivial evening with four quarts of beer inside him, his blood vessels still contain three quarts of water with a one per cent concentration of dissolved substances. The throat, the stomach, the muscles, and the skin may be dry, but the blood vessels are not.

Reservoirs of the Body

Conversely, a person may fill himself with extremely large quantities of water, as much as four, six, or even ten quarts of water, as in certain types of diabetes, yet he cannot dilute his blood by even one twentieth of one per cent. If a Lilliputian were to stand on the bank of a blood vessel and observe the height of the blood-stream, he would never notice any change. He would not know whether it was summer or winter outside, whether the individual was thirsty and wanted a drink, or whether he was standing at a bar and finishing his seventh drink. Figure 206 illustrates schematically the manner in which this marvellous regulation of water metabolism functions.

Where Does the Imbibed Fluid Remain? Let us look at the diagram [Fig. 206]: (a) is the intestine, (b) the liver, (c) the heart, (d) the muscle, (e) the kidney, (f) the bladder, and (g) one of the many metabolic centres situated in the depths of the brain, in this case the water centre. Those parts shaded by parallel lines are the places where water collects; the stippled canals are the blood-filled vessels. The diagram shows a man who has had four litres (nearly $4\frac{1}{4}$ quarts) of beer. His blood remains undiluted. One litre of fluid is in the intestine (a), and another litre has passed through the intestinal blood vessels into the liver, filling this organ (b). The liver is a large fluid reservoir inserted between the intestine and the circulatory system, which intercepts fluid absorbed by the intestine in order to protect the blood. It is the reservoir of the circulation. For this reason the liver swells after the ingestion of fluids.

Next to the liver the muscles form the second largest fluid reservoir of the body. Man carries fifty-five pounds of muscle on his body. These distensible muscle fibres are capable of absorbing large quantities of water. The muscles are by far the greatest water reservoir of the body. They can absorb from the circulation as many as thirty quarts of water. The third of the four litres of beer in our diagram has vanished into the muscles (d).

Filters

The kidneys are attached to the circulation. They filter the blood, removing from it both water and salts, which pass into the bladder as urine (f). The fourth litre of the imbibed beer is to be found in the kidneys and in the bladder — but there is none of it in the blood!

The Water Centre. The regulation of the water exchange between the liver, muscles, and kidneys is carried out by a "lock-keeper" situated in the brain, in the form of a nervous apparatus called the water centre. In the depths of the brain lie a number of nerve centres that regulate metabolism and are therefore known as

metabolic centres. The blood flows past them, and the individual nerve apparatuses are adapted to a certain content of metabolic products—protein, sugar, fat, water, salt, phosphorus, calcium, carbon dioxide, urea, etc.—in the blood. By analogy with the water level the blood content of these various substances is referred to as their blood "level"; thus one speaks of a blood sugar level, or a blood calcium level. These centres are united by means of nerve connections with the organs that are important for the metabolism of the substance in question. The water centre is connected with all the organs, but especially with the muscles and kidneys (I and II).

We can see how the blood flows around the water centre, which is adapted to a certain water content of the blood. If the liver gives up some of the fluid received from the intestine, thus raising the water level of the blood, the water centre stimulates the muscles by way of nerve path (I) and they absorb water. At the same time, by way of nerve path (II), it stimulates the kidney to excrete water. This stimulation continues as long as the liver gives off water to the circulation. The bladder is filled, the individual evacuates the excess water; more water passes into the atmosphere through the skin and lungs. In this manner the excess fluid, the four litres of beer, are soon eliminated through the urine, the fæces, perspiration, and exhaled air. But the water level of the blood has remained the same.

Intravenous Infusion. The rapid regulation of the water balance in the body is most strikingly exhibited when fluids are introduced directly into the veins in the form of an intravenous infusion. If an individual has lost too much blood, or if the blood vessels are paralysed and flaccid as in shock, so that the blood collects in the abdominal area, and the heart has not enough fluid left to

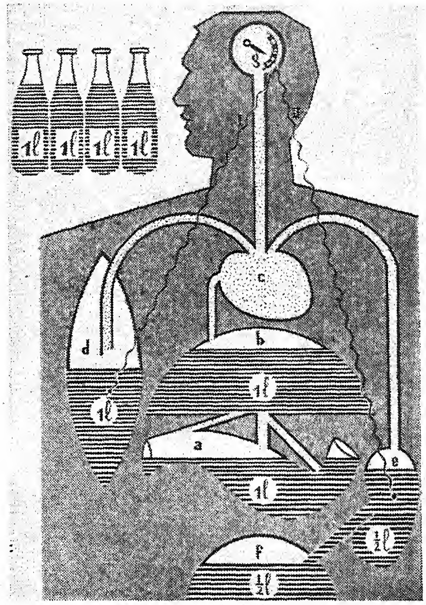


FIG. 206. *No matter how much liquid is drunk, the blood is not diluted thereby, nor is its quantity increased. The surplus water is stored in the intestine (a), the liver (b), the muscles (d), the kidney (e) and the bladder (f). The nerve tracts (I) and (II) communicate with the water centre (g) in the brain; (c) is the heart.*

pump through the circulatory system, it becomes necessary to fill the blood vessels artificially. This is done either by transferring blood from one person to another (*blood transfusion*), or by introducing a saline solution through a vein in the arm (*intravenous infusion*). While one or two quarts of fluid may be introduced into the vessels in this manner, yet the normal quantity of blood is not augmented in any considerable

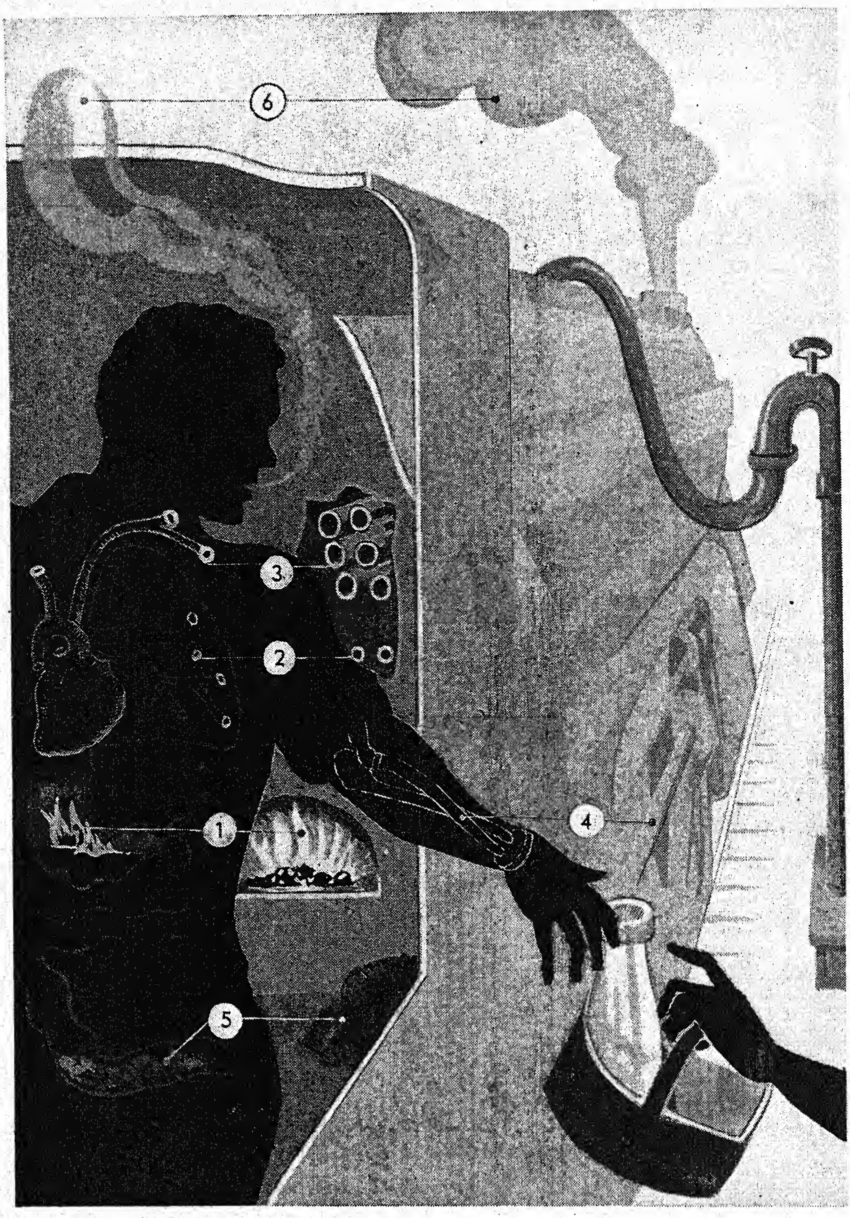


FIG. 207. *Both man and machine use plant products containing carbon for fuel (1). They consume the fuel through the addition of oxygen (2), utilize the heat obtained in this way, and get rid of the carbon dioxide produced in the course of this process (6). The heat is distributed by a fluid (3) circulating in pipes and is employed to operate levers and joints (4). The non-combustible residue is eliminated as ashes or fœces (5). The conversion of food substances into energy inside the body is called metabolism.*

degree. As soon as normal vascular tension is reached, a good part of the excess is automatically taken up by the liver, muscles, and kidneys. Like the body and every organ in it, the blood resists any attempted change in its basic composition or structure.

Combustion and Oxidation. The source of energy for both the machine and the organism is combustion—that is, the splitting of the large fuel molecules with the aid of oxygen. Combustion in a machine is essentially the same as that in a living body, but the manner in which it takes place is different. During combustion in inanimate nature the splitting of the molecules is a violent, anarchic, catastrophic process; in living organisms it takes the form of a systematic, orderly breakdown.

We take a match and light it. Apparently a commonplace act, yet it is actually an extremely exciting play. If we only had microscopes with magnifications of a million times so as to be able to see this microcosmic drama! For it is a drama that takes place. Like comets the oxygen atoms rush into the molecular solar systems; the circling planets are stopped in their paths; and the heat created by this sudden cessation increases their temperature to catastrophic heights. The internal energies are set free with explosive force, producing heat, light, and flaming fire—the match burns. The burning of a molecule of matter is a microcosmic upheaval.

Mild Process

So-called combustion of substances in the metabolism of organisms is very different. Neither fire nor deadly heat is produced, but rather a mild, precisely regulated warmth. This is an indication that no catastrophic processes are taking place here, but rather chemical transformations proceeding in accordance with definite laws. Combustion in the organism is a ferment process. There are combustion ferments whose function it is to bring about the union of oxygen and fuel, producing orderly, regulated oxidation of the fuel.

Ferment "Cannon"

The ferment of oxidation can be compared with a cannon which hurls oxygen atoms into the solar system of the molecule in order to shoot individual planets out of the system. The solar system is not destroyed by a cosmic catastrophe, but is "taken apart." As each planet is knocked out of the system it gives up a part of its energy for the metabolism of the body.

Fat Metabolism. Best known is the chemical mechanism of fat metabolism. The fatty acids form chains, which for purposes of illustration may be compared with watch-chains [Fig. 205]. A large molecular group is suspended from each end of the chain; between them is a chain consisting of small links, each representing a simple CH_2 group. The complexity of a fatty acid depends on the number of these links. The fats of the human body are fatty acids with fourteen to sixteen links. In the oxidation of a fatty acid one link after another is knocked off the chain, until the chain between the watch and the watch-charm has disappeared. Then these two large pieces are also split up into carbon dioxide and water.

The oxygen molecule which knocks the links off the chain is represented as a chisel; the ferment which sets the chisel in motion as a hammer. The number of links removed from the chain, and the

rapidity with which this process occurs, depend on the blows of the hammer—that is, the ferment. By means of the agency of ferments the organs regulate the intensity of the oxidative processes. If heat or some other form of energy is required, the cells produce corresponding quantities of oxidation ferment to furnish the hammer-blows directed against the links of the chain.

Sugar and Insulin

Sugar Metabolism. The actual fuel and motor substance of the body is sugar. All the carbohydrates in our food (flour, bread, cake, noodles, rice, farina, potatoes, oats, sugar, chocolate, honey, fruits, jellies) are broken down in the intestinal canal to grape sugar and in this form pass through the portal vein into the liver. Here the grape sugar is stored as the starch of the body (glycogen).

Insulin. The transformation of the dissolved grape sugar into glycogen is carried out by means of a substance secreted by the pancreas in the blood, with which it circulates through the body and reaches the liver. This substance is known as insulin. It has received this name because it is not produced by the actual gland tissue of the pancreas, but rather by a second gland within the former in the form of islands (Latin: *insulæ*) in the pancreatic tissue. In lower vertebrates these two glands are separate structures, lying alongside each other; in the higher vertebrates, however, they are combined as described [Fig. 193 (3)]. Insulin is a substance like the ferments, but is secreted in the blood and not in the intestinal canal like the pancreatic juice. Gland products that act like ferments and are secreted in the blood-stream are known as hormones. Insulin is the hormone of the pancreas. Its function is the transformation of soluble grape sugar into glycogen. Since it circulates with the blood, it is found everywhere in the body and is effective in all organs, especially in the liver and the muscles. Beyond the intestinal canal the liver is the first reservoir for water and the first storehouse for carbohydrates, which are mainly consumed by the muscles.

Protein Metabolism. The cell is a protoplasmatic machine, consisting chiefly of protein and using carbohydrates for fuel. It does not generally use protein for fuel, but like every machine it has a certain amount of wear and tear. The human body uses up $1\frac{3}{4}$ ounces of protein daily, which must be replaced by means of food. The fate of the ingested protein in the body is so varied that it is impossible to follow it in detail. The ingested protein is deposited in the liver, spleen, muscles, bones, etc., and is withdrawn whenever protein is needed somewhere in the body. If an individual starves or has a fever, he loses protein.

Protein Reserves

However, in the course of starvation not all the organs lose weight and protein at an equal rate. Those organs most necessary for the maintenance of life—the heart, the brain, and the respiratory muscles—remain unweakened and undergo very little loss of weight. Protein passes from the resting organs into the blood, from which the working organs (heart, lungs, and brain) withdraw it for nourishment. Nor does a fœtus starve in the uterus, for it withdraws as much food as it needs for its growth from the mother's blood, without regard to the latter's needs.

CHAPTER XXV

Nutrition

THE CALORIE. CALORIC REQUIREMENTS. PROTEIN REQUIREMENTS. THE NUTRITIVE VALUE OF FOOD. DIGESTIBILITY. QUICK LUNCHES. THE FAMILY MEAL. THE MIDDAY REST. NUTRITION AND OCCUPATION. VALUABLE AND INFERIOR PROTEIN. THE NUTRITIONAL BALANCE SHEET.

EVERYONE eats, and everyone thinks he knows why he eats. Science does not know why. Science does not yet know what sort of motor a cell actually is, and consequently does not know in what manner this cell motor transforms the food substances which it receives into energy. Therefore it is also unable to say why man eats, and why the cell requires just these and no other food substances in order to function properly. For these reasons science is unable to offer us any complete theory of nutrition. At present science occupies itself with the collection of facts. The most important results of research in this field have been collected below in the form of thirty-five theses.

The Calorie

1. The breaking down of the food in the tissues is carried out with the help of ferments in the form of oxidation reactions—that is, combination with oxygen.

2. Although the body is certainly not a combustion engine precisely like that used in technology, yet owing to a lack of any better units of measurement, and because the laws of energy apply with equal force in both cases, food is evaluated as a "fuel," and so is rated in calories.

3. The large calorie, which in dietetics and throughout this book is referred to simply as a calorie, is 1,000 times the calorie used in physics and is that quantity of heat required to heat 1 litre of water 1° centigrade. On a good gas range this takes about six seconds. If one places a pot containing 1 litre of water on the stove and waits until it boils, approximately 100 calories have been supplied for this purpose [Fig. 208].

4. In an ideally constructed machine 427 kilogrammes can be raised 1 metre by means of 1 calorie. With the 100 calories required to bring 1 litre of water to the boiling-point, an individual can be transported up a hill 500 metres (1,640 feet) high.

5. 1 gramme of protein or carbohydrate (starch, sugar) furnishes 4 calories, and 1 gramme of fat 9 calories.

6. Just like a steam-engine, the human body is entirely indifferent to the nature of the fuel from which it derives its heat of combustion. For this reason the three food substances are mutually interchangeable in their capacity as fuel. 100 grammes of fat can replace 225 grammes of protein or carbohydrate.

Caloric Requirements

7. When absolutely at rest the body needs 1 calorie per kilogramme

of body weight per hour to maintain life. Thus a person weighing 70 kilogrammes requires as an absolute minimum to maintain his daily existence $24 \times 70 = 1{,}680$ calories.

8. The caloric requirements increase with the work performed by the body. Even the intake of food signifies an increase in the work performed by the body, since the food must be raised, chewed, swallowed, and moved about in the stomach and intestine; the glands must produce digestive juices, etc. For persons resting and taking meals in bed the daily caloric requirement rises from 1,680 to 2,000 calories. Light work requires approximately 3,000 calories or more, and heavy labour may demand as many as 8,000 [Fig. 210].

9. People everywhere require approximately the same number of calories, as many in Mexico as in Finland. Similarly, occupational requirements are more or less the same everywhere. Home workers use up 2,500 to 2,800 calories, factory workers, peasants, and soldiers require 3,000 to 3,400, and heavy workers such as miners, foundry workers, smiths, and navvies, need 4,000 calories or more per day.

10. Heat loss increases the caloric requirements. In comparison with their content small bodies have a comparatively larger surface area and consequently lose more heat. Children need more calories than adults. Since the oxidative processes in the body of an aged person become weaker, such an individual needs fewer calories than someone in the prime of life. In winter the caloric consumption is greater than in summer; on windy days it is higher than on quiet days; and greater in people who work outdoors than among those who work in closed rooms.

11. Theoretically a person's daily requirement can be satisfied by 350 grammes of fat (100 grammes = $3\frac{1}{2}$ ounces approximately), or 800 grammes of protein, or 800 grammes of carbohydrate.

12. But the digestive apparatus is adapted to a mixed diet of protein, fat, and carbohydrate. It is unable to digest daily either an isolated quantity of 350 grammes of fat or 800 grammes of protein.

13. The normal fuels of the body are the carbohydrates, starch and sugar, but, remarkably enough, the body stores in the liver and muscles only 300 grammes—that is, one third of its daily requirement. If more carbohydrates are ingested, they are transformed into fat.

Protein Requirements

14. In order to replace the daily protein loss, man must ingest a minimum quantity of protein. This is known as the protein minimum, and amounts to about 50 grammes.

15. However, machines and organisms attain a maximum of achievement only when they receive not simply a minimum of fuel, but a certain excess. The human body achieves its maximum when it receives approximately 100 grammes of protein daily. Actually, people all over the globe, in so far as they have enough to eat, instinctively consume 100 to 125 grammes of protein.

16. The normal food requirements of a working man of medium weight are 50 grammes of fat, 100 grammes of protein, and 600 grammes of carbohydrate daily.

Nutritive Value of Food

17. The composition of various foods with respect to their protein, fat, and carbohydrate content is re-

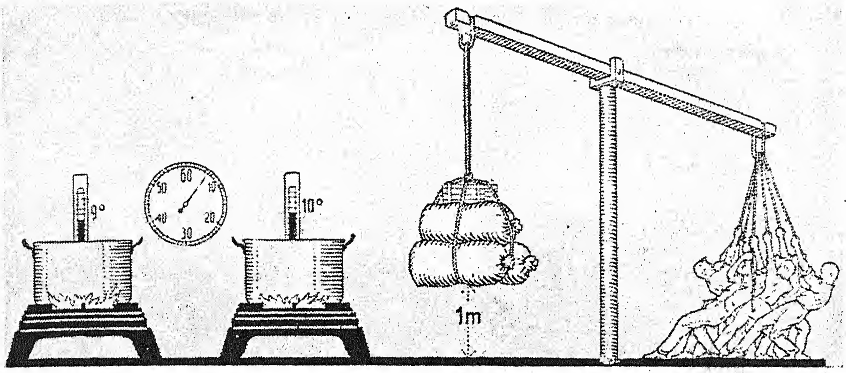


FIG. 208. *The large calorie is a measure of both heat and energy. In the first place, it is the amount of heat required to raise the temperature of one litre (slightly more than a quart) of water 1 deg. centigrade. Secondly, the large calorie is the amount of energy needed to raise a weight of 427 kilogrammes to a height of one metre.*

presented sometimes in tabular form. Such tables present the composition of various foods in an interesting manner, but their practical utility is limited. In the first place, they almost always present the composition of raw foods, but man consumes very few foods in a raw state. A raw potato has practically no nutritive value, for man does not eat raw potatoes. When man eats potatoes he consumes something very different from that represented in the table as a potato. He eats a potato that has been peeled, boiled in water, and mixed with fat and salt, or vinegar and oil.

In Figure 209 is presented a comparison of the nutritive content of raw potatoes with fried potatoes. In the latter the protein content has been tripled, the carbohydrate content quadrupled, and the fat content has been increased four hundred times. The caloric value is now seven times greater. In place of tables containing the nutritive values of foods, we should have them for the various dishes that we eat. But even such tables would be of limited usefulness because of the varying food values.

Varying Nutritive Value

18. The nutritional content of foods varies greatly. The nutritional content of the potato depends on the variety, the season, the condition in which it is bought, and the treatment to which it is subjected in preparing it for consumption. A new potato has a different nutritive value from an old potato; a fresh one has a very different structure from one that has been in storage for many months; a potato grown in dry soil or during a dry year has a different water content from one grown in a moist environment. Yet even a most precise determination of a prepared food omits still another factor.

Digestibility

19. Man does not live on what he eats, but rather on what he digests. The body is not nourished by what we ingest, but by what passes from the intestine into the blood.

Preparation of Food

20. The nutritive value depends

on the preparation. Carefully prepared foods have a higher nutritive value than those indifferently prepared. Of 100 grammes of boiled peas, 60 grammes are digested. If they are carefully puréed so that all the skins are removed, 80 grammes are digested, and absorbed.

A meal that has been carefully prepared at home by a mother and adjusted to the tastes of the individual members of a family so that it is eaten with pleasure has a very different nutritive value from the same quantity of food thrown into a pot by a cook and set on the stove to boil. Biologically good home cooking is quite different from food prepared in large quantities for masses of people, which must cook much longer and may be ready many hours before it is eaten.

"Compatibility" of the Food

21. The nutritive value of the food depends also on the digestive power of the individual. There are people who digest fat poorly because of a weakness of the pancreas, while others are unable to assimilate a coarse diet, which must undergo digestion slowly, because the intestine reacts too strongly to it and evacuates the food particles, enveloped in hard capsules of cellulose, before the cellulose is diluted by the

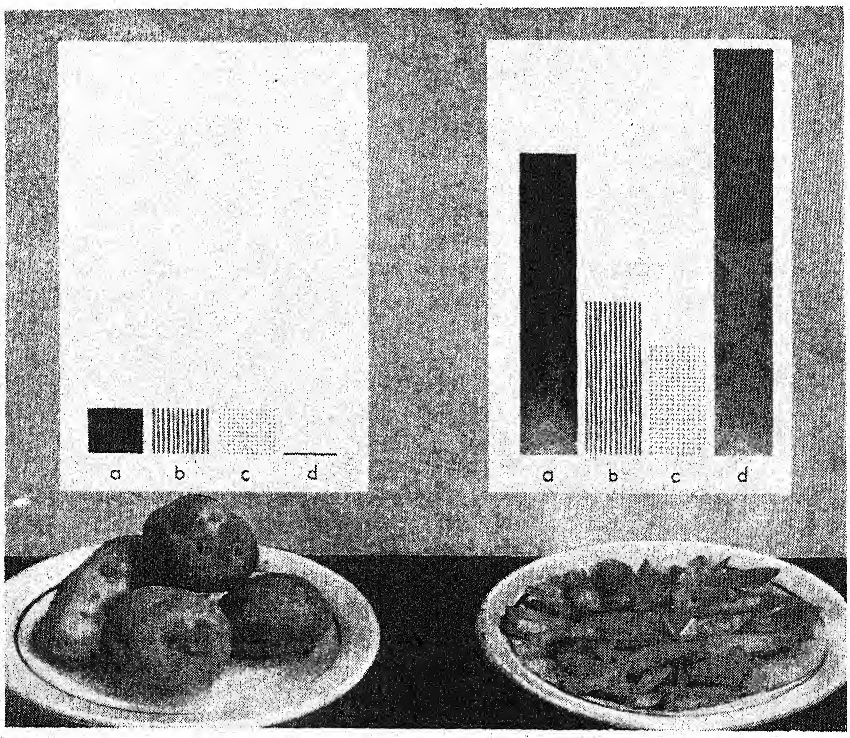


FIG. 209. *Cooking may affect the nutritive value of food considerably. When potatoes are fried, the caloric content (a) is increased 7 times. The amount of starch (b) is increased 4 times, of protein (c) 3 times, and of fat (d) no less than 400 times.*

bacteria of the large intestine. Some people, therefore, are unable to digest whole-wheat bread, cereals, beans and peas. Each individual has his or her peculiarities—and in this sense each one of us requires an individual table of food values. Everything that one digests with difficulty or that passes through the intestine too rapidly has little nutritive value.

"Too Tired to Eat"

22. The nutritive value of food is further dependent on the degree of fatigue of the digestive apparatus. Eating requires considerable labour. It is well known that eating makes one feel warm. In order to accomplish this work the body must have the necessary energy. On this account one should not sit down to eat as soon as one comes home, but should rather rest awhile before doing so. This is particularly important in the case of delicate children who must be well fed, and of people who are under weight. Before meals they should rest for fifteen minutes; they should breakfast in bed, and stay there for half an hour afterwards.

Quick Lunches

23. The nutritive value of food also depends on the rapidity with which it is eaten. If you gulp your food while standing, or in a noisy restaurant where your attention is distracted from the enjoyment of the food by the clattering of plates, the busy waiters, and the general unrest, or where you must wait impatiently for service, your glands function poorly and their secretions are weak. Every argument at the table, every annoyance, and naturally also reading during a meal, interfere with the work of the glands and the quality of the secretions which they pour out.

The Family Meal

24. For food to be well digested and assimilated it must be eaten in a congenial atmosphere. In this respect the family meal must be regarded as ideal. Eat your meal in peace and quiet, and you will not only enjoy yourself but also obtain much more energy and nourishment.

The Midday Rest

25. After eating, the digestive apparatus must be permitted to rest. If a person rushes right back to work or gets into a car for a long drive immediately after a meal, the food will naturally be poorly digested.

Nutrition and Occupation

26. Food must be adapted to the individual's needs. A person working out of doors needs a different diet from one whose occupation keeps him indoors. A worker performing heavy labour requires a diet that will furnish many calories and fill his intestinal canal so that he will feel satisfied for a long time despite the rapidity of digestion.

Valuable and Inferior Protein

27. The value of food depends not only on the quantity but also on the quality of its proteins. The body is supposed to repair its cellular motors by means of the component fragments of protein. There are many different kinds of protein. Every plant and animal species has its special kinds of protein. The more the ingested food resembles human protein, the greater will be the quantity of useful components that the body will find in it, and the fewer will be the reconstructions that it will find necessary to carry out. A

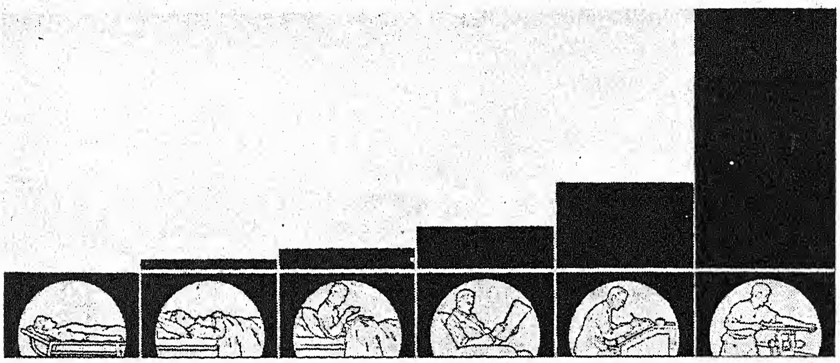


FIG. 210. *The daily caloric requirements, under varying conditions, of a man weighing 70 kilogrammes (about 150 pounds). The minimum requirement, during complete rest, is 1 calorie per kilogramme every hour, or 1,680 calories in a day.*

vegetable diet contains components that cannot be utilized by the human body and are excreted by the kidneys. One hundred grammes of protein derived from meat are more valuable than an equal quantity of carrot protein. People praise the protein content of legumes, but they forget that only fifty per cent can be utilized by man.

Must Food be Nutritious?

28. The value of a food is not exclusively due to its nutritive value. There are foods that are valuable not because of their fuel value or protein content but because of other qualities. A lemon is a food of inestimable value because of its acids, its vitamins, and its taste substances. In 1795 the use of lemon juice was made obligatory in the British Navy and thus thousands of seamen were saved from the horrors of scurvy. Yet a lemon is not nutritious. There are many similar foods of which we use such small quantities that it is entirely unimportant whether they are nutritional or not. Many of the foods bought in a delicatessen are not used to satisfy hunger, but to stimulate the appetite, and to make us hungry. Food is not only a necessity, but also a pleasure. Brillat-Savarin begins his famous *Physiology of Taste* with the statement: "An animal feeds; man eats; a civilized person dines."

Nutritional Balance Sheet

29. In order to determine the true nutritional value of a food, one must draw up a balance sheet like a business man, deducting all expenses that are incurred—until the food is absorbed by the intestinal villi—as nutritional loss from the gross nutritional gain.

Nutritional Loss in Buying

30. The first nutritional loss arises from the energy required to obtain the food. If a worker who performs heavy labour buys an expensive cauliflower for his supper, then he has expended more energy to obtain it than he will get back from its nutritive substances. He may receive 380

calories from the cauliflower, but if he has expended 520 calories to obtain it, then he has sustained a loss.

Loss Due to Preparation

31. The second nutritional loss arises from the energy required to prepare the food. Cake tastes good and is nutritious. But a good cake is expensive, and it is probable that the breadwinner of a family must furnish more calories and body protein to earn the money for the cake than he will receive in return. Besides, it means a lot of work for the housewife. She must go shopping, and if she forgets something, she may have to go again. She must prepare and mix all the ingredients, the eggs, butter, salt, sugar, and flour. She must knead the dough and prepare it for the oven. Then while it bakes she must watch it. All in all, a great deal of work, and at the end she has one cake on a plate. The food chemist may find the cake nutritious —but in terms of household economy, it certainly is not.

Loss Due to Waste

32. The third nutritional loss arises from food wastes. If one buys a cheap fish, one carries home twice as much as will later be eaten. Bones, head, scales, fins and viscera must be deducted. If vegetables are boiled and the water poured away, considerable quantities of the nutritive content are poured down the drain.

Loss Due to Digestion

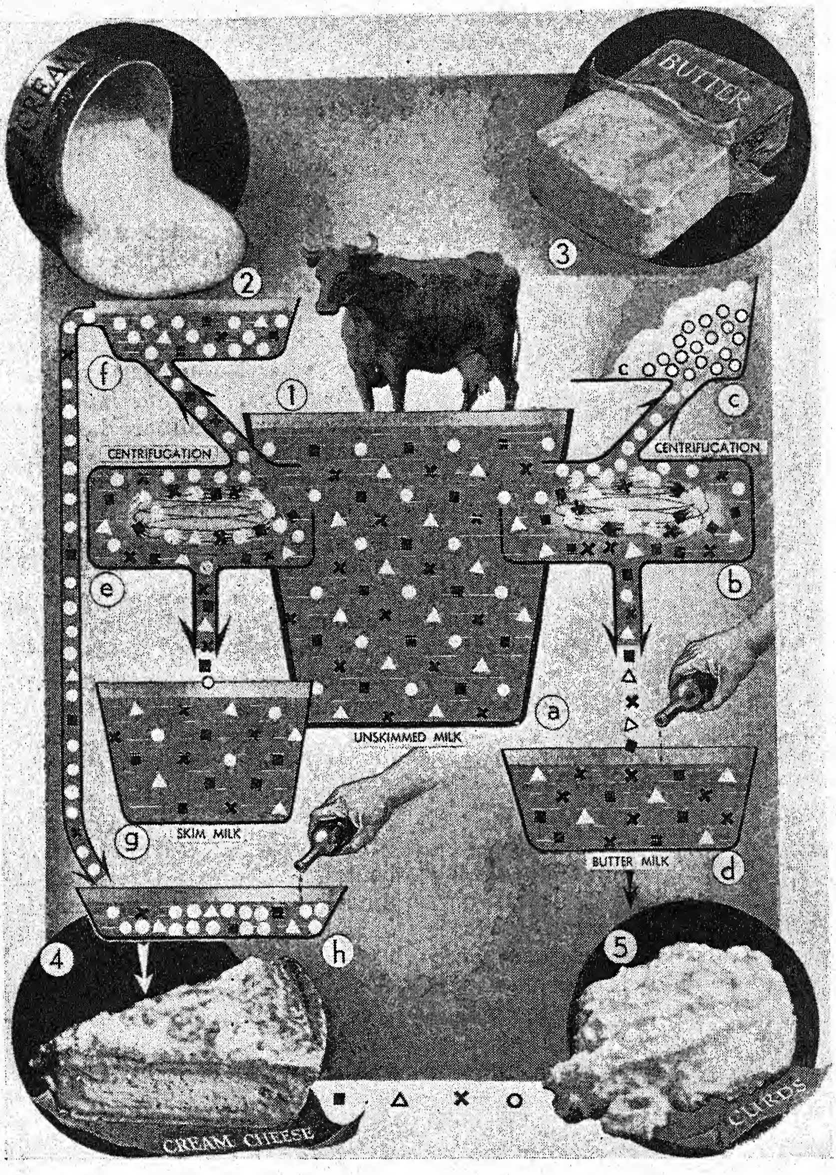
33. The fourth nutritional loss arises from the labour required for digestion. All the work that an individual has to perform, from the first contraction of his arm and jaw muscles until the nutritive substances pass into the liver, must be subtracted from the nutritional value of the food lying on a plate.

Loss Due to Reconstruction

34. The fifth nutritional loss is a result of molecular reconstruction. Not only the food as a whole, but every molecule is broken down and rebuilt. The reconstruction of a molecule is bound up with as relatively large a loss of energy as the reconstruction of a house. A molecule of starch when ingested is first broken down in the intestine to grape sugar, rebuilt in the liver to starch, then broken down again to grape sugar so as to be transported by the blood, once more built up as glycogen in the muscles, and finally converted again into grape sugar before being oxidized. According to chemical calculations these various reconstructions consume five per cent of the molecular energy. If the carbohydrate is not immediately consumed, but first transformed into fat and deposited in the body, the energy loss amounts to ten per cent. By far the most complicated are the reconstruction processes of protein metabolism. It has been calculated that the energy loss for protein amounts to approximately thirty per cent.

The Teachings of Dietetics

35. As is generally realized, dietetics is not a simple study, but is full of problems. Such standards as calories or protein content do not do justice to the facts. These are so complex that in practice such standards are only useful as guideposts and should not be regarded as immutable truths that apply in all situations. Above all, do not attach too much value to any special "theories of nutrition," for they usually contain very little solid truth



MILK AND ITS VALUABLE PRODUCTS

FIG. 211. *The chief constituents of cow's milk (a) are albumin, casein, calcium and fat. If the milk is centrifuged, or churned (b), the fat (c) can be removed in the form of butter (3). The remaining fat-free fluid is buttermilk (d). If an enzyme is added to the latter, the protein and calcium clump together to form curds (5), which may be pressed into cheese. Moderate centrifugation (e) yields cream (f). The residue is skim milk (g). Cream cheese (h) contains fat as well as protein and calcium.*

CHAPTER XXVI

Foods

CLASSIFICATION OF FOODS. THE MENU. THE FIRST COURSE. THE MAIN COURSE. SALADS. BREAD AND POTATOES. SWEET DESSERTS. FRUIT. CHEESE. COFFEE, TOBACCO AND LIQUEURS. MILK. CASEIN.

THE classification of foods according to their origin in the plant or animal kingdom is of little value. Caviar granules are eggs—in biology, but not in the kitchen. Foods are substances performing a certain function and should consequently be classified accordingly, as, for instance:

1. Digestive fluids, which furnish the body with the necessary fluid for the preparation of digestive juices: soups, beverages, gravies, salads, compotes.

2. Appetizers (sour, salty, sharp, and spicy titbits), which "crank up" the digestive apparatus by means of their taste.

3. Nutritive foods, which take care of the protein and caloric needs of the body: bread, meat, fish, potatoes, vegetables, farinaceous foods, rice.

4. Foods that produce a sense of satiety because of their volume and the difficulty with which they are digested. Among these are cabbage, turnips, potatoes, farina, dumplings, noodles, dark bread, etc.

5. Digestive aids that stimulate the digestive organs: e.g., sharp gravies, salads, pickles, salt, pepper, mustard, and onions.

6. Foods that retard digestion owing to their large sugar or fat content, thus extending the feeling of satiety over a longer period: e.g., fat gravies, cream, sweets, sweet desserts.

7. Foods that remove any aftertaste of the foods eaten. In this category are compotes, fruit, nuts, and desserts.

8. Stimulants, which stimulate the brain, thus creating a feeling of excitement: e.g., coffee, tea, tobacco, and alcohol.

9. Thirst-quenchers. They quench thirst partly by giving the body fluid, and partly by paralysing the feeling of thirst: e.g., water, beer, wine, lemonade, fruit, ice cream.

The Menu. Man does not feed on protein and carbohydrate, nor does he eat isolated foods. Instead he partakes of various food mixtures. Even such a fairly simple dish as a ham and egg sandwich contains four foods derived from a chicken, a hog, a cow (butter), and a grain plant. Nor are the dishes eaten alone. On the contrary, the various dishes are eaten as parts of a meal and are arranged in a certain succession. This forms the menu of a meal.

The First Course. A meal often begins with *hors-d'œuvres,* which implies something considered as extra and apart from the work of digesting the meal itself. The first course is intended to "tune up" the digestive apparatus, to stimulate the muscles and glands so that the subsequent food will not pass into a dry stomach, but into one containing a moving lake of digestive juice [Fig.

212]. For this reason it consists of foods that generally present a pleasant appearance when served so as to stimulate the appetite—that is, the salivary and gastric glands. Such foods are red tomatoes, yellow lemons, green salads, hard-boiled eggs cut in slices, and garnished canapés. In order to stimulate the tongue, hors-d'œuvres are strongly spiced and are sometimes served with small quantities of a dry wine, since large quantities of alcohol paralyse the digestive glands, while small quantities stimulate them.

Soup. The purpose of the soup is to dilate the vessels of the mouth and the stomach by its warmth, to "tune up" the glands by means of the spices in it, and to supply the body with fluid, for during the next few hours several quarts of digestive juice will pass from the glands into the intestinal canal [Fig. 213]. While a soup may contain nutritive substances, they are not essential to a good soup. Bouillon, for instance, is almost devoid of any nutritive substances, and yet it is of great value for the digestive process.

"Warming Up" the Digestion

Intermediate Dishes. Similarly, it is not the function of those courses that are served between the soup and the main course to furnish nutritive materials, but rather to enable the diner to pass the time in a pleasant manner. The glands have been stimulated by the hors-d'œuvres, the soup has supplied the digestive fluids, and now a pause should be intercalated until the digestive apparatus is fully active. This period is analogous to those few minutes when an automobile driver, after having started his motor, allows it to run for a short while to warm it up. The foods eaten during this period should not be too satisfying—for example, trout, crabs, oysters, small fowl, asparagus, artichokes [Fig. 214].

The Main Course. Now comes the main dish, which is the only one that should contain large quantities of nutritive substances: protein, fat, and carbohydrates. For this reason the main course generally consists of meat (protein), vegetables (carbohydrates), and gravy (fat). The main course should require vigorous chewing, so that the diner's muscles will tire, producing a feeling of satiety.

Satisfying Foods

While only a few light meat and fish varieties are chosen for preliminary courses, the main course usually consists of fat fish, such as salmon, eel, or carp, or the heavier kinds of meat and fowl, such as venison, goose, turkey, steaks, roasts. The vegetables served with the main course are also of the same character: for instance, potatoes, cabbage, turnips, legumes, chestnuts, and the various stuffings for roast fowl. The main dish should not only be nutritious and require vigorous chewing, but should also remain in the stomach long so as to prolong the feeling of satiety [Fig. 215].

Gravies. In the first place, gravies supply fluid to the chewing mouth, so that the substance of the main dish, which is being chewed vigorously, can be swallowed. Secondly, when they are correctly prepared with spices, they are appetizers that stimulate the glands, increasing their secretion. Thirdly, owing to their fat content, they can also retard digestion. Thus a housewife must know what the function of the gravy is to be at a particular meal. If she

wants to stimulate digestion, the gravy must have a low fat content, but be spiced. On the other hand, if she wants to have the feeling of satiety produced by the meal last longer, she should add fat to the gravy so that it will retard digestion.

Vegetables. The most important constituents of vegetables are their salts, the chlorophyll, which is closely related to the blood pigment, the vitamins, and the valuable protein substances in the cell nuclei of the young plant parts. Since the salts are extracted by the water in which vegetables are prepared, and are transformed into insoluble compounds when cooked too long, vegetables should not be subjected to long cooking nor should the water be poured away. Instead the vegetables should be steamed in their own juices and eaten as soon as they are ready. The occasional eating of raw vegetables is to be recommended, but they must be young, otherwise they will be poorly digested.

Salads. Salads consist of raw vegetables and as such are extremely valuable when eaten in small quantities. Sunlight, rain water, and the salts of the earth are mixed in them to a true elixir. Because of their high water content, salads are beverages in solid form. They supply the body

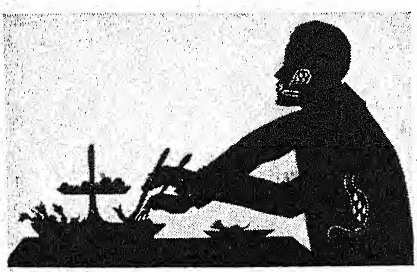


FIG. 212. *Hors-d'œuvres stimulate the appetite—through the digestive glands—by their colour, aroma and taste.*

with fluid for the digestive juices and refresh the mucous membranes after the main course. By means of such additional substances as vinegar, lemon juice, or mustard they stimulate the digestive glands. Salads are rich in valuable vitamins and per-

FIG. 213. *Soup supplies the body with warm fluid that helps the digestive glands to prepare their secretions.*

mit us to ingest olive oil, which is otherwise unpalatable [Fig. 216].

Bread and Potatoes. Bread and potatoes are the two most important fat "carriers." It makes little difference whether one kind of bread contains more or less protein than another, or whether it is more or less easily digested. Bread and potatoes are valuable because they must be chewed well, and are eaten with butter, honey, cheese (on bread), and butter, fat, milk, cream, and gravy (with potatoes).

Sweet Desserts. The first part of a meal is dominated by salt, the second part by sugar. Salt stimulates digestion, sugar retards it. For this reason sweets are prohibited before the main course, but are desirable thereafter, so that the feeling of satiety will remain longer. If one wants to be able to eat again soon, sweets should be avoided. On the other hand, if one wants to remain satisfied for a long time, a meal should be ended with a sweet, and

possibly also a rich dessert [Fig. 217].

Removal of the After-Taste. After having finished the main course of a meal, the diner endeavours to get rid of the taste of the food. This is an important aspect of every meal, and has been developed to an extremely refined technique in the culinary art. For this purpose five different methods are used.

1. Drying. By means of foods of coarse consistency that can be characterized as rubbing substances, the tongue is massaged and the taste pits cleaned out. Crumbs of apples, pears, grapes, nuts, and almonds pass like brushes and brooms over the surface of the tongue and sweep it clean. They lie like pieces of cloth or blotting paper over all the crevices in the surface of the tongue and empty them by absorbing their contents.

2. Rinsing. By means of fruit juices, compotes, beverages, and ice cream, fluid is poured over the tongue to clean it, just as one washes the floors in a house.

3. Cauterizing. The acids and tannin of apples, pears, plums, grapes, strawberries, gooseberries, lemons, oranges, and almonds cauterize the tips of the papillæ on the tongue and dull the ends of the nerves so that they are no longer sensitive.

4. Pasting. By means of pasty substances, such as gelatine, syrup, and cream, that are added to sweet desserts, the taste pits are pasted together. At the same time, this produces a prolonged sensation of sweetness which covers the taste of the main dish.

5. Spicing. The taste apparatuses for bitterness are most deeply situated and well hidden, so that a bitter taste remains longest with us. In order to achieve a prolonged after-taste, spices, such as cinnamon, vanilla, almond oil, coffee, and cocoa, are added to desserts.

Fruit. The nutritive content of fruit is minimal, since it contains more than ninety per cent water. Fruit is a "solid" beverage. An orange is a cup full of orange juice given to us by nature. Of the solid substances in fruit, one half is cellulose. It swells in the intestine, fills it, and increases the amount of fæces. In the first place the fruit acids have a refreshing effect; secondly, they remove any after-taste by cauterizing the taste buds; and thirdly, they have a laxative action. An apple is a mild laxative, a combination of chemically

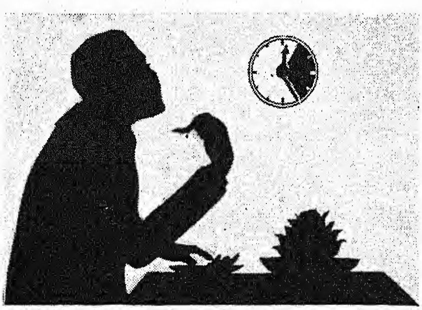


FIG. 214. *The light intermediate dish provides a respite for the digestive glands to prepare fresh gastric secretions.*

FIG. 215. *The main dish supplies the body with nutriment and, filling the stomach, leaves a feeling of satiety.*

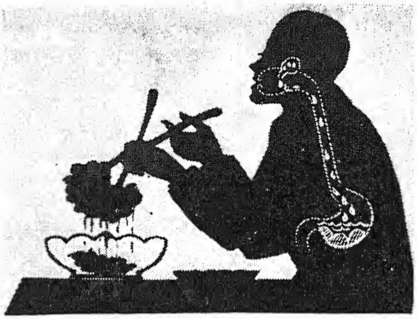


FIG. 216. *The salad supplies the body with water and stimulates the tired digestive glands to renewed secretion.*

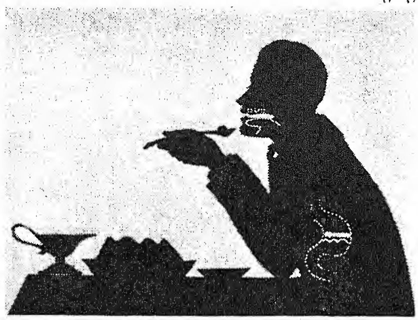


FIG. 217. *The sweet dessert removes the after-taste; it also helps to retard digestion and so promotes a feeling of fullness.*

stimulating acids and substances that swell, exerting a physical effect. Only very few varieties of fruit, such as nuts and bananas, supply the body with any considerable quantities of nutritive material. Important, on the other hand, is the fact that fruit is rich in vitamins, salts, and certain structural elements of protein. For this reason fruit is especially valuable for growing children and convalescents, who must replenish their depleted supplies of these substances. Because of these qualities fruit is an ideal dessert. The juice rinses the mouth, the crumbs massage the tongue, cleaning all the crevices of the tongue and oral cavity, and

FIG. 218. *Coffee and tobacco produce protracted taste effects, stimulate the intestine, and dissipate fatigue.*

finally the acids cauterize the tips of the nerves and assuage the heated mucous membrane of the mouth. In addition, the acids clean and disinfect the teeth, so that fruit, apart from its other values, can be regarded as an ideal instrument for oral hygiene, as a combination of mouthwash, toothpaste, and toothbrush presented to us by nature. The old custom, practised by many people, of eating an apple at night before going to bed is an instinctive utilization of these advantages, which are combined in an especially favourable form in the apple.

Cheese. Many and particularly cultivated diners choose cheese as a dessert, because it is an excellent remover of any after-taste. Since it is difficult to swallow, it compels one to chew vigorously, so that the dry crumbs clean the tongue and palate thoroughly. The sharp, spicy substances in different cheeses stimulate the glands, and their tart taste does not disappear very soon. Brillat-Savarin says: "A meal without cheese is like a girl without eyes." If the cheese is spicy it aids digestion; if the fat content is preponderant, it retards it. Each variety of cheese has its particular biological qualities. On

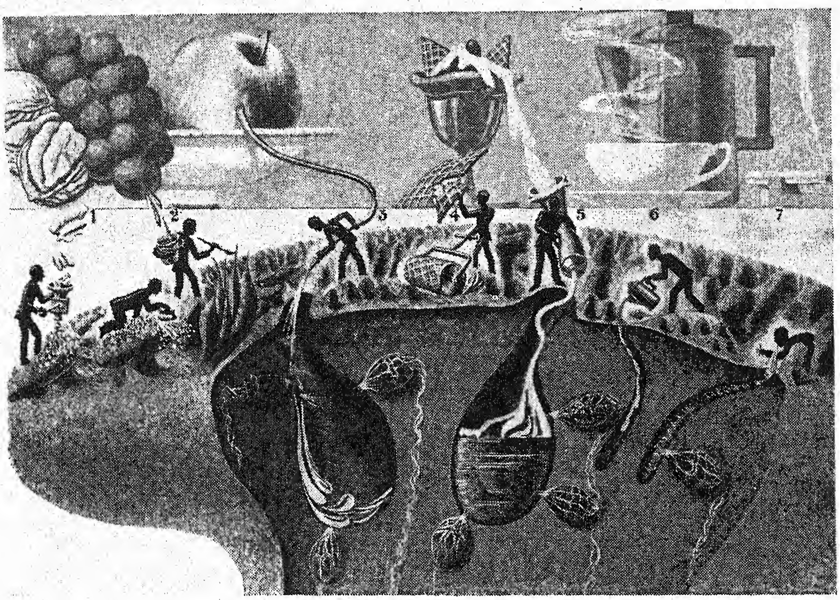


FIG. 219. *How the dessert cleans the tongue. (1) Nut particles sweep and brush the papillæ; (2) fruit acids dull the tips of the papillæ; (3) fruit juices wash out the taste pits; (4) bakery products dry the floor of the tongue; (5) sticky foods, like gelatine or syrup, paste together the wide taste pits; (6) coffee fills the narrow taste pits at the back of the tongue with bitter substances; (7) tobacco smoke fumigates the crevices.*

account of its high protein content, cheese is one of the best sources of protein for man. Besides, as a milk product it is rich in minerals, especially calcium and phosphorus. If one wants to remain satisfied as long as possible after a meal, a very fat cheese should be eaten as a dessert.

Coffee, Tobacco, and Liqueurs. Coffee, tobacco, and liqueurs are stimulants with which a meal is concluded. They are not foods, for they do not nourish. Nevertheless, they are valuable, for they exert a strong stimulatory effect on the palate, increasing the flow of saliva and aiding gastric activity. They stimulate the movements of the intestine, thus helping to overcome the feeling of fullness after a meal [Fig. 218]. At the same time these substances also stimulate the cerebral cortex and in this way counteract the tired, sleepy feeling that accompanies digestion after a meal. They remove inhibitions, excite the imagination as well as a need for conversation, and in this way contribute to the sociality and conviviality of an occasion. These substances demonstrate very well that a food may lack completely any nutritive value, and yet play a valuable rôle in the work of digestion within the body, as well as in the individual's enjoyment of life. Once again we see that the problem of nutrition cannot be solved with calories, protein tables, and vitamin content alone.

Milk. Within the mother's body the developing child is provided by the maternal blood with oxygen for

respiration as well as with nutritive materials for growth. After birth the child breathes independently, but it still receives nutritive material from its mother—with her milk. The maternal milk replaces the blood by means of which it was previously fed. For this reason milk resembles blood; it is, indeed, blood without any respiratory substances—that is, without red blood cells and blood pigment. In fact, it may be regarded as white blood. There is no food, with the exception of animal blood, that can compete with milk as far as its richness in nutritious materials is concerned. In the course of research investigations of milk no less than 125 constituents have been isolated. Among these are water, protein, fats, sugar, salts, hormones, ferments, vitamins, copper, manganese, arsenic.

Cow's Milk and Human Milk. Cow's milk is intended for a calf and not for a human child. A calf is a much coarser creature than a baby. Thus cow's milk is also much more coarsely constituted. When it is examined with an ultra-microscope the protein molecules appear as hazy spots of light. In human milk they are not as easily visible, for the groups of protein molecules are much finer. When an infant regurgitates cow's milk, coarse cheese clumps appear; when a child fed on human milk vomits, fine flakes appear.

Casein. Among the many protein substances contained in milk, casein is most important. When digested, it furnishes the greatest number of fragments (amino acids) for the construction of new protein molecules. Casein is the "universal" structural element for the construction of the youthful body. It is a "youth" protein, since it is found only in milk, the food of growing mammals, and in eggs, the food of developing birds. A calf doubles its body weight seven weeks after birth; a human child does not do so until it is twenty-five weeks old, because cow's milk contains about three times as much casein as human milk [Fig. 220].

Albumin and Globulin. Two other proteins may be obtained from milk. They are known as lactalbumin and lactoglobulin, and resemble closely the albumin and globulin of blood serum.

Milk Salts. The milk of every animal species contains various salts in concentrations appropriate to the developmental needs of the young of the species. The more rapid the growth of the newborn, the greater is the salt content of its mother's milk

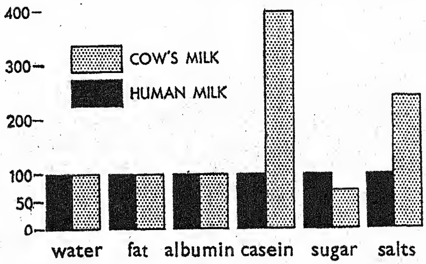


FIG. 220. *How human milk differs in its composition from cow's milk.*

[Fig. 221]. A rabbit doubles its original weight at birth in 6 days, a dog in 9, a sheep in 14, a goat in 22, a cow in 47, a horse in 60, and man in 180 days (see numbers on white circles). Cow's milk is too rich in proteins and salts for the feeding of young children and must be modified to adapt it to this purpose.

Not only the quantity, but also the kind of salts contained in milk is important. In human milk 77 per cent of the phosphorus is in the form of organic compounds similar to those present in the body. In cow's milk

only 28 per cent of the phosphorus compounds are of an organic type. To utilize the phosphorus of cow's milk the child's body must make much greater efforts than when it attempts to metabolize the phosphorus of its mother's milk.

Colostrum. The first milk that the mother produces after birth is poor in fat, watery, and very salty. It has a laxative effect on the intestine, and causes the evacuation of meconium, the first fæcal discharge after birth. This first milk is called colostrum.

Milk as a Food for Adults. For older children and adults milk is an unexcelled food, when consumed as part of a mixed diet. Milk is the only food which supplies the body with considerable quantities of nutritive material in the form of a potable liquid, and, on the other hand, it is the only fluid that is transformed in the stomach to a solid mass, cheese. Milk is the only food for which the stomach has special digestive ferments; and milk fat is the only fat that is broken down in the stomach and absorbed there. Finally, milk is one of the few foods that can be almost completely digested in their raw state, without need of cooking.

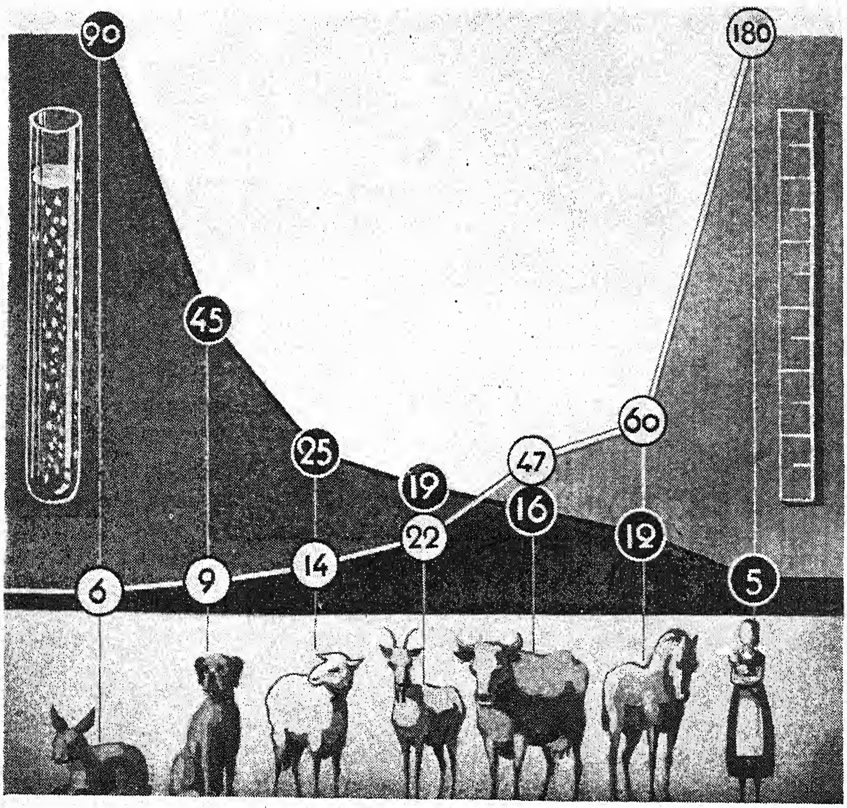


FIG. 221. *Each kind of mammal provides milk suitable for its young. Figures on black circles indicate the proportion of salt in the milk. Figures on white circles show the number of days from birth required to double the body weight of the animal.*

CHAPTER XXVII

Mineral Substances

WATER. SALT. SALT-FREE DIET. CALCIUM. PHOSPHORUS. SULPHUR. POTASSIUM ARSENIC. MANGANESE. COPPER. BROMINE. IODINE. IRON.

BESIDES proteins, fats, and carbohydrates, food must also contain a number of other substances, of which the most important are water, mineral substances, and vitamins. The body contains approximately 50 quarts of water, and loses about 3 quarts daily through the urine, fæces, perspiration, and respiration. Man ingests only part of this water as fluid, since the so-called solid foods in his diet also contain a high percentage of water. Fruits and vegetables contain more than 90 per cent water, potatoes 80 per cent, eggs and meat 70 per cent. Even bread contains on an average 35 to 40 per cent of water. The idea of the Greek philosopher Thales, that water is the primary substance, appears to be true [Figs. 222 and 223].

Salt. Since the body fluid is not pure water, but rather a salt solution, and since the body continually excretes salt solutions with the urine, fæces, perspiration, and tears, man must constantly ingest adequate supplies of salt to make up the loss.

"Sea Water" in the Body

Plants do not contain sufficient salt for human requirements. Salt is water-soluble and consequently passes into the rivers and oceans with rain water, so that the solid land and with it the plant world are poor in salt. The salt of the earth's surface is dissolved in the oceans, which contain so much salt that the surface of the earth could be covered with it. Land animals, however, are the descendants of organisms that arose and lived in the primordial seas of the earth. The body fluid of these creatures was sea water, and they retained it when they emigrated to dry land at a relatively late period. Thus, while land creatures live in a milieu which is relatively deficient in salt, the organization of their bodies has remained that of sea animals, and they have retained "sea water" as their body fluid. Consequently, they must transform the water found on land into sea water by adding salt to it.

The "Salt God"

Carnivores obtain salt from the body fluid of their victims. For this reason, carnivores, in contrast to herbivores, do not desire salt and will even reject food containing an excess of it. This is also said to be true of Eskimos, whose diet consists almost exclusively of meat. Salt is highly esteemed among inland peoples. Each year the ancient Mexicans selected the most beautiful maiden to become the bride of the salt god, and it was considered one of the highest national honours to be sacrificed to him. In antiquity wages were often paid in salt. Our word "salary" is derived from the Latin word for salt. Holbein was

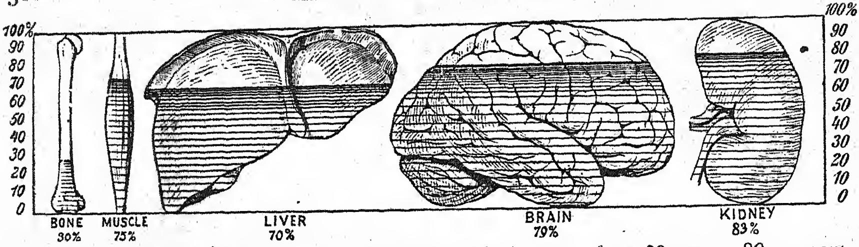


FIG. 222. *The human organs are largely composed of water—from 30 to over 80 per cent.*

paid in salt for one of his Madonnas. If a prisoner is long deprived of salt, he suffers terribly, and is ready to accede to any demands in order to obtain some salted food.

In the body fluids, salt is contained in solution, and its molecules form electrically charged particles known as ions. The charges upon these ions render them particularly reactive chemically. They confer electrical conductivity upon the solutions in which they are contained, since they carry a current while moving through a solution. These ions of the body fluid play a decisive role in the vital processes of the organism.

Salt-Free Diet. The chief depot of salt in the body is the skin. If an individual is fed on a salt-free diet, the blood loses its salt through the urine, perspiration, fæces, etc. Under these circumstances the skin must give up its reserves to the blood, so that the latter can maintain a constant concentration of salt. Thus a salt-free diet leads to a depletion of the salt reserves of the skin. Such a depletion has a favourable influence on various skin diseases, especially on lupus, tuberculosis of the skin. This observation led to the introduction of the salt-free diet in the treatment of tuberculosis. Salt is eliminated chiefly by the kidneys. If the kidneys are sick, the physician tries as far as possible to protect them against any undue activity. For this reason kidney patients are given a diet containing little salt.

Calcium. The body contains about three pounds of calcium, most of which is deposited in the bones. Calcium has a sedative effect on the cells, nerves, and brain, because it contracts the ultra-microscopic pores in the cell walls. For this reason calcium is prescribed as a sedative. In regions that are poor in calcium the inhabitants are more prone to dental maladies and fractures of the bones. A frequent cause of calcium deficiency in most urban communities is the common practice of softening "hard" water by removing the calcium from it. "Hard" water con-

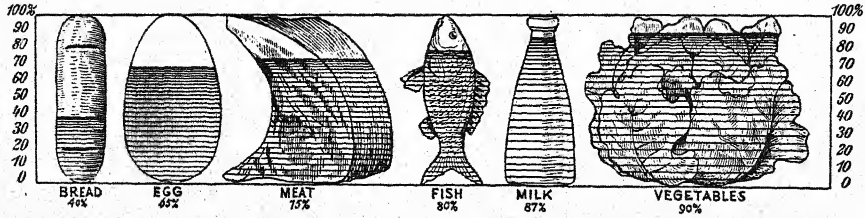


FIG. 223. *Most solid foods contain a far greater proportion of water than is generally imagined. They furnish a large part of the body's water requirements.*

taining calcium is not popular in either industry or the home. When "hard" water is used in a steam boiler, heavy deposits of *boiler crust* settle on the tubes of the boiler, interfering with the transference of heat from the metal to the water. When "hard" water is used for washing, much soap has to be dissolved before the necessary lather can be secured.

Defects of Soft Water

Soap, composed of a mixture of the sodium salts of several organic acids, forms insoluble compounds with calcium. For these reasons "hard" water is artificially softened by removing its calcium. This practice may be detrimental to the health of the population, since foods lose part of their calcium when boiled in water with a low calcium content [Fig. 224]. A portion of potatoes such as is usually served with the chief meal of the day, contains about one gramme of calcium (Ca). If the potatoes are cooked in "soft" water with a low calcium content—e.g., containing only one-hundredth as much calcium as in the potatoes—they will give up about two-thirds of their calcium to the water, retaining only one-third (*Left*). Conversely, "hard" water with a high calcium content gives up some of its calcium to the potatoes so that when they are ready to be consumed they contain three grammes instead of one gramme (*Right*).

The ideal calcium-containing food is milk. One quart of cow's milk contains almost two grammes of calcium! In order to protect oneself against any depletion of calcium and protein in the body, there is no better remedy than to drink at least one glass of milk daily or to eat such easily digestible milk products as cottage cheese, buttermilk or yoghourt.

Phosphorus. Three quarters of the calcium in the body is combined with phosphorus in the form of calcium phosphate. Phosphorus is an extremely strong poison, yet the body contains almost two pounds of it. In the course of its first year of life an infant ingests no less than fifty grammes ($1\frac{3}{4}$ ounces) of phosphorus, a quantity sufficient to poison an entire village. In biology, however, the concept of poison is not quite the same as in a chemist's. Pure phosphorus is a poison, while phosphorus contained in chemical compounds is generally not toxic. Milk has a phosphorus content—one fiftieth of a gramme in each quart of cow's milk—since it is intended to furnish materials for the development of bone, which consists chiefly of calcium phosphate. Furthermore, meat, bread, potatoes, and legumes are also rich in phosphorus.

Assimilating Phosphorus

It is recognized that phosphorus compounds of milk and meat are more valuable than those of plants, however, since they are similar to the constituents of the body and are assimilated to a very large extent without any reconstruction, while the phosphorus compounds of plants for the most part pass undigested through the intestine. Besides the bones, phosphorus is contained in complex protein and fat compounds, which are apparently indispensable for the highest vital processes, since they are present in essential structures of the cell and the body, in the cell nuclei, in the sex cells, and the nerve cells. The best-known phosphorus fat is that known as lecithin.

Sulphur. The body contains 100

grammes of sulphur. Every cell contains a trace of sulphur, but most of it is present in the brain, the nails, and the hair, red hair having the highest sulphur content. If the body lacks sulphur, the hair and nails become brittle. For sick hair and nails there is no better medicine than to eat daily a plate of hulled oats, which have a high sulphur content. Eggs, beans, lentils, radishes, onions, garlic, and chives also have a high sulphur content. While we do not know the precise function of sulphur in the metabolism of the body, yet it is interesting to note that since ancient times foods containing sulphur have enjoyed a reputation for special therapeutic properties.

In order to obtain some idea of the work of a mineral substance in the body, let us trace the metabolism of sulphur as represented diagrammatically in Figure 225. First let us look at the diagram. Five paths are represented in it, and each one is characterized by a different line. The first path, with the black numbers, leads from (1) to (5); the second, with the white numbers in the black circles, from (6) to (10); the third, with the black numbers in the white circles, from (11) to (13); the fourth from (14) to (15); the fifth, with the white numbers in the black squares, from (16) to (18).

Compounds of Sulphur

The first path, from (1) to (5), leads through the alimentary canal. The sulphur which is ingested in the form of eggs or some other food is digested in the alimentary canal, and forms hydrogen sulphide in the large intestine. The foul odour of the intestinal gases and the fæces after the ingestion of food containing sulphur is due to the presence of this gas.

The second path, (6) to (10), leads from the intestine to the liver. Here the sulphur is combined with an amino acid, forming a compound known as cystin. Cystin can reach any part of the body and participate in the vital processes as an amino acid. In Figure 225 we have assumed that it travelled to the fingernail (10), and participated in the building up of the nail substance.

The Human Laboratory

The third path (11) to (13), arises in the muscle, where sulphur-containing amino acids like cystin are present. In the course of metabolism these acids give off carbonic acid and are simultaneously transformed into a compound called taurin, which flows into the liver. Here it combines with the metabolic products of the phosphoric fat cholesterin, and this double compound, taurochol, passes with the bile into the intestine.

The fourth path, from (14) to (15), shows how the sulphur compounds of the blood wander to the salivary glands. Here the sulphur unites with potassium cyanide to form potassium thiocyanite, which may be detected in the saliva. This seems to be a defensive mechanism by means of which the body protects itself against the poisonous cyanides.

The fifth path, (16) to (18), is taken by a part of the taurin in the liver. Some of the taurin is changed in the liver to sulphuric acid, which combines with products of protein metabolism related to phenol. These double compounds of sulphuric acid and phenol leave the body by way of the kidneys.

For most of us it is probably quite a revelation to learn that sulphuric acid, phenol, and potassium cyanide circulate in the blood. But one need

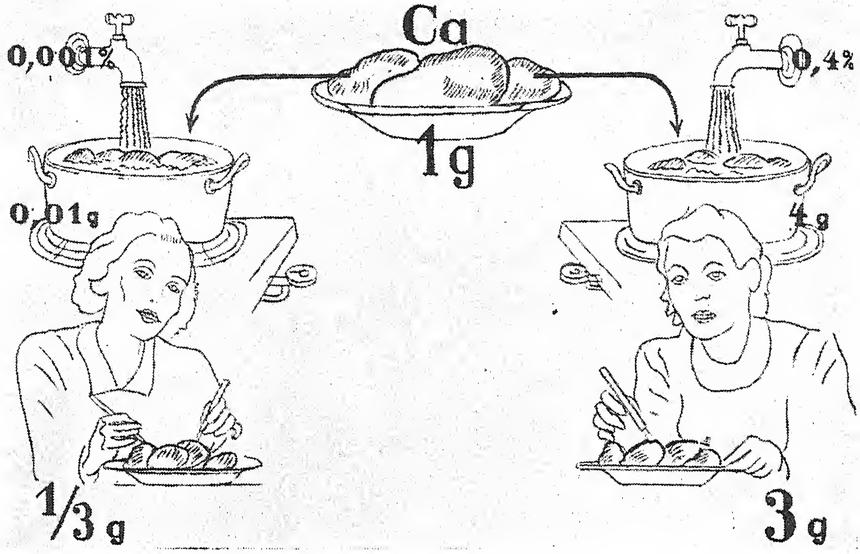


FIG. 224. *Potatoes cooked in soft water (Left) may retain only one-third of their original calcium. On the other hand, cooking in hard water may treble the calcium content (Right).*

have no worries on this account. These "deadly poisons" have circulated in the blood vessels of the human body for millions of years, and were present in our own bodies even before we were born. The human body is indeed a remarkable machine, in which it is quite natural for sulphuric acid and potassium cyanide to circulate without destroying it. One may even go so far as to maintain that they must circulate in the machine so that it may function.

Potassium. In contrast to sodium, potassium is soluble only with difficulty; and is consequently not stored in sea water or in the soil. The potassium requirements of plants are quite large, so that potassium salts are used to fertilize the soil.

Among common foods the potato has the highest potassium content—1½ ounces of potassium in 1 stone of potatoes. Potassium is a dangerous poison, when injected directly into the blood; and considered objectively, potatoes are more poisonous than wine or coffee. If the potassium contained in an ordinary portion of potatoes were injected into the bloodstream, it could kill a man. But it never reaches the blood. A large part remains with the cellulose in the intestine, and leaves the body in an undigested state. The assimilated potassium is stored in the liver, and only released into the blood in the same minimal quantities in which it is excreted by the kidneys at the other end of the circulation. As a result the blood hardly notices the introduction of this dangerous substance. Legumes are also rich in potassium, and what has been said of potatoes is also true of them. The potassium of meat, however, acts very differently. On cooking meat a considerable portion of the potassium leaves the meat and passes into solution. Meat broth is a kind of potassium "tea." Small

quantities of potassium pass very rapidly into the blood from the meat broth and produce a stimulatory effect on the organism. Thus the custom of beginning a meal with meat broth or bouillon is justified by dietetics.

Arsenic. Arsenic is one of the most deadly poisons that we know. Most poisoners have used arsenic for their crimes, since even one tenth of a gramme may be fatal. The very toxic but also therapeutically very effective remedies against a number of tropical diseases, as well as the best remedy for syphilis, Salvarsan, are arsenic compounds. The body can accustom itself to arsenic, as to any other poison, if it is consumed gradually.

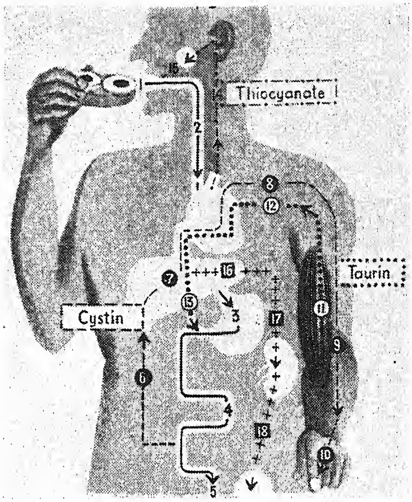


FIG. 225. *How sulphur travels through the body and forms specialized compounds in the organs (Page 312).*

Arsenic Eaters

Because arsenic exerts a stimulatory effect and improves a person's stamina, ability to work, and general condition, mineral springs containing arsenic are highly esteemed. The inhabitants in the neighbourhood of such springs are so accustomed to these waters that they can ingest as much as half a gramme of arsenic per day. Arsenic acts very vigorously on the bone marrow and is used therapeutically in almost all blood diseases. It is apparently indispensable for the development of the blood cells, since the fœtus in the uterus is supplied with surprisingly large quantities of arsenic.

Manganese and Copper. Manganese and copper are present only in traces in food. They accompany iron, and like it participate in the manufacture of the blood pigment and the blood cells. In addition there seems to be some relation, as yet unclarified, between copper and the gastric wall.

Bromine. It has been suggested that bromine plays a part in the functioning of the nervous system, but this is doubtful. We do know, however, that it is one of the most widespread sedatives used in cases of nervousness.

Iodine, see Chapter XXXI.

Iron, see Chapter XII.

Anyone who lives rationally on a mixed diet, and consumes milk, cheese, fruit, salads, and vegetables in his daily diet, automatically supplies his body with mineral substances adequate for its demands.

CHAPTER XXVIII

Diets and Vitamins

WHAT DIET IS MOST SUITABLE FOR THE HUMAN BODY? RAW FOOD. A VEGETARIAN DIET. MEAT DIET. A MIXED DIET. AVITAMINOSES. VITAMIN A. NIGHT BLINDNESS. VITAMIN B. VITAMIN C. SCURVY. ULTRA-VIOLET RAYS. VITAMIN D. RICKETS. VITAMIN E. RIBOFLAVIN. VITAMINS T, H, K, AND P. THE VITAMINS AND THE ORGANISM.

THE human digestive apparatus is adapted to a mixed meat and vegetable diet. Man's dentition contains the canines of a carnivore, the incisors of a herbivore, and the molars of a graminivorous animal. He has salivary glands for both meat and vegetable diets. He has special digestive ferments for meat proteins, and others for carbohydrates. His intestine is not so long as that of herbivores, nor so short as that of carnivores. His cæcum is not so large as that of the horse, yet it has not vanished completely, as in the cat.

Diet for the Average Man

That man's digestive tract is undoubtedly adapted to a mixed diet is further demonstrated by studies of human metabolism. A diet consisting of approximately 70 grammes of protein, 100 grammes of fat, and 500 grammes of carbohydrate is most suited to the "average man." This is possible only when man eats plant and animal foods in the form of a mixed diet.

Raw Food. A raw food diet—that is, food eaten raw without having come into contact with fire—generally consists of vegetables, salads, fruit, nuts, vegetable fats, as well as certain grains such as oats that can be rendered edible by softening. A somewhat expanded raw-food diet may contain milk and eggs, food that actually belongs to a "meat" diet.

The Disadvantages of Raw Foods. Such raw foods are poor in protein, calories, salt, and acids. On the other hand, they are rich in vitamins, ballast substances, and mineral substances, which for the most part cannot be made available for the body. While an individual may be able to live on such a diet of raw food, he must consume very large quantities to cover his protein and carbohydrate requirements. The proteins contained in these raw foods are foreign to the human body. For the most part, they cannot be assimilated by the body at all, or they must first be subjected to considerable internal molecular reconstruction. Besides, these proteins are bound to the cellulose husks and can be separated from them only with great difficulty.

Danger of Protein Shortage

Owing to the large mass of raw cellulose contained in them, a considerable portion of such raw foods passes undigested and unassimilated through the digestive canal. The serious possibility of protein deficiency which may occur if such a diet

is continued for a long period can be avoided by drinking buttermilk, which is rich in protein. Actually buttermilk is a meat product, a "fluid meat."

Furthermore, when living on a diet of raw vegetables the body must itself perform all the work generally performed by the process of cooking in a kitchen. It must manufacture greater quantities of digestive fluid in its glands, the intestine must work harder to cope with the very large quantities of coarse food, the kidneys must excrete the excess mineral substances that cannot be eliminated, and so on.

Loss of Salt and Water

Plants have a high potassium and a low sodium content. Potassium removes water from the tissues. If an individual changes to a diet of raw plant foods, he loses several quarts of water within a few days and with it approximately fifty grammes of salt. This loss of water decreases the burden on the circulation, and the loss of salt does the same for the kidneys and the skin, the skin being the chief depot for salt. In certain selected cases a raw-food diet is an excellent therapeutic instrument. However, for a normal working individual it is a rather irrational diet.

A Vegetarian Diet. A vegetarian diet, strictly speaking, is a diet comprising exclusively plant products. However, such meat products as eggs, milk, butter, cream, and cheese are usually added. Like the raw-food diet, a vegetarian diet is relatively poor in calories and protein, but since the foods are cooked the number of calories that become available and their nutritive values are incomparably greater. A vegetarian must also ingest relatively large quantities of food in order to cover his basic needs, since plant foods, owing to their high cellulose content, are not as well assimilated and require more work in chewing, secretion of digestive fluids, and intestinal movement. The digested protein substances are foreign and consequently inferior to those of meat. On this account all herbivorous animals have specially developed digestive apparatuses: the giant grinding teeth of elephants, the crops of grain-eating birds, the muscle stomachs in chickens, the rumination mechanism of the cow, and the long intestine of the horse. Nevertheless, the digestive process requires a great deal of time, and almost all herbivorous animals do little else but eat and rest after eating. One need only compare the life of a rabbit with that of a dog in order to obtain a graphic conception of the different "modes of life" of herbivores and carnivores. A silkworm consumes about 25 pounds of mulberry leaves in order to attain a weight of 0.1 ounce; a leech, on the other hand, can live nine months on one meal of blood.

An Undecided Question

Whether a vegetarian mode of life offers any advantages to compensate for its many disadvantages is still an open question. At present it is still unproved, and on the whole rather improbable.

Meat Diet. There are individuals who live exclusively on meat—for instance, the Polar peoples and the inhabitants of coasts and islands having little vegetation. These peoples are in comparatively good health and probably live as long as people elsewhere. We know of several Polar explorers who lived on meat and blubber for as long as seven years and

suffered no harm. Scientific experiments during which human beings were fed for as long as two years exclusively on meat led to similar results. The widespread opinion that the consumption of meat is harmful is completely unproved. If a meat diet were harmful, there would be nô carnivores in nature, and if man had been " intended " by nature not to eat meat, he would have no mechanisms within his body for the digestion of meat. Considered objectively, meat is without any doubt an important and useful food. It contains protein in the form of molecules similar to those of the body, also mineral salts and vitamins, as well as the valuable blood pigment. Of all foods it requires the least amount of work for digestion, and is also best assimilated. It leaves only minute residues. With the increase and development of world commerce and the rise of the standard of living throughout a large part of the world, the consumption of meat has increased extraordinarily. During the last century it has grown at least ten times greater.

A Mixed Diet. Man is naturally adapted to a mixed diet. It is characteristic of man that he is not as unilaterally specialized as most animals. He can accomplish many things. He can run on a level surface like a horse, and also climb trees like an ape. He can live in the tropics as well as in the Arctic. Man can accomplish more with his hand than any other creature, nor is he simply an animal dependent on a single sense organ, either the nose, the eyes, or the ears. Indeed, one may say that man can do almost everything. And along with these other natural qualities he possesses the ability to chew a great variety of foodstuffs and to digest them with his medium-sized intestine. This profusion of natural qualities coupled with the adaptability of man is at the basis of man's rise to his present state.

Besides protein, fat, carbohydrates, water and minerals, man's food must

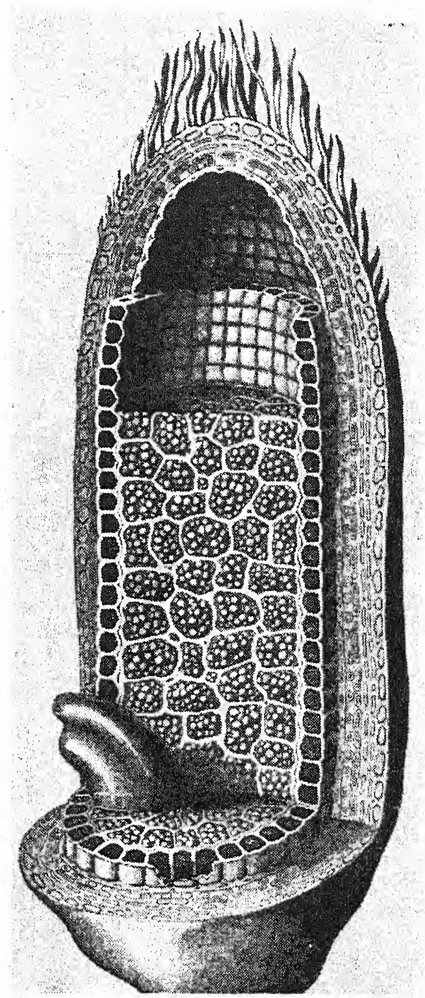


FIG. 226. *Wheat is one of the staple foods of mankind. Every day countless millions of wheat grains are ground into flour, and each one of them has a complicated internal structure like that of the grain above.*

contain still other substances known as vitamins, because they are indispensable for the maintenance of life (*vita*). Vitamins are substances formed by plants or animals which must be supplied to the body in minute quantities so that the vital processes may continue undisturbed.

Avitaminoses. Lack of vitamins causes diseases known as avitaminoses. Some of these deficiency diseases have been known for centuries—for example, rickets and scurvy. Indeed, empirical methods of treatment had been developed for scurvy and rickets long before vitamins were discovered and their causal connection with these conditions elucidated. Thus John Woodall, an English naval surgeon of the seventeenth century, recommended the use of lemon juice as a preventive and curative measure for scurvy. Similarly cod-liver oil has been used for the treatment of rickets for more than a century. The vitamins exercise a remarkable regulatory effect upon various fundamental metabolic processes of the body—for example, bone formation. In the absence of vitamins neither proteins, fats, carbohydrates, nor salts are properly utilized in the body.

Eight Principal Vitamins

It is probable that vitamins belong to the oldest products of living creatures, for they are also produced by the lowest creatures—the bacteria, algæ, and yeasts. At present there are eight vitamins definitely known to be of significance for the human body. These are vitamin A; the vitamin B complex, containing B_1, nicotinic acid, and riboflavin; and vitamins C, D, E, and K.

Vitamin A. Together with the green-leaf pigment, chlorophyll, plants also contain a yellow-red pigment which is found in particularly large quantities in carrots, and which has therefore been named carotin. Like chlorophyll it is formed in plants through the action of sunlight [Figure 227]. Carotin enters the stomach (1) in green plants such as spinach, lettuce, cucumbers, and in coloured fruits and vegetables such as carrots, tomatoes, and berries. From the intestine (2) it passes to the liver (3), where it is converted into vitamin A, probably through the action of an enzyme called carotenase. From the liver vitamin A is then distributed to all the organs by the blood stream (4, 5).

Seeing in the Dark

The precise action or function of vitamin A in the body is still unknown, but evidence suggests that it functions in chemical combination with other substances. There is some evidence that vitamin A is necessary for the proper function of the eye in adapting itself to vision in the dark. The retina, or light-perceiving background, of the eye contains a reddish substance known as visual purple. When the retina is exposed to light this substance becomes bleached and its colour disappears. In darkness, however, the pigment reforms and the original colour returns. It is generally believed that visual purple is a sensitizing pigment which enables the eye to see objects in a dim light. If the regeneration of visual purple is disturbed, the affected individual is unable to see in the dark; he is " night-blind."

Night Blindness. This condition is found among groups and peoples whose food contains little carotin—for example, among the poor hunting tribes that inhabit the steppes

FIG. 227. *The formation of vitamin A and its action upon the body. Sunlight causes carotin to form in certain plants, such as carrots, tomatoes, lettuce, and spinach. When man eats these plants, carotin passes from the stomach (1) through the intestine (2) to the liver (3). Here the carotin molecule is split into two molecules of vitamin A. The vitamin then passes into the blood stream and travels to all parts of the body (4, 5). In the eyes (5) carotin takes part in the formation of "visual purple," a deficiency of which leads to "night blindness"—the inability to see in a dim light.*

of Russia. During the first World War the Danes sold their butter and other dairy products to the belligerent countries, while they ate margarine. Because of a lack of carotin, and consequently of vitamin A, many of them became night-blind.

It has long been known that night blindness is benefited by the administration of cod-liver oil. Hippocrates, the father of medicine, recommended the therapeutic use of ox liver dipped in honey. The Turkomans of Central Asia combine this empirical therapy with magical rites. They boil a ram's liver and after various mystical ceremonies feed it to the patient. More recent evidence has confirmed that some substance present in the liver and in certain fats is concerned with the regeneration of the visual purple. Since the liver is the organ which stores the carotin of the food and transforms it into vitamin A, it seems possible that a lack of this vitamin is the cause of night blindness.

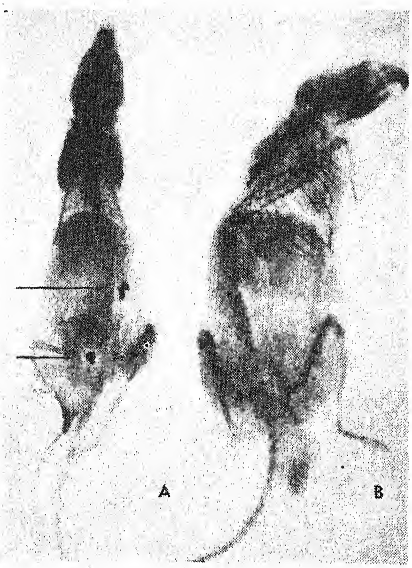


FIG. 228. *By feeding rats on food lacking vitamin A, stones can be made to form in their kidneys and bladder, as the X-ray photograph at (A) reveals. On adding vitamin A, the stones disappear (B).*

Vitamin A Deficiency. It is characteristic of the vitamins that each of them performs several functions. In addition to its rôle in the regeneration of the visual purple, vitamin A also has other functions. If the body lacks vitamin A, a pathological condition of the eyes known as xerophthalmia is produced. The cornea dries up (Greek: *xeros*, dry) and becomes ulcerated and inflamed.

Vitamin A deficiency also leads to changes in the mucous membranes of the respiratory, alimentary, and genito-urinary organs as well as in the eyes and the tear glands. A healthy mucous membrane is able to withstand infection and oppose bacterial attacks. However, vitamin A deficiency predisposes to bacterial infections, and it seems likely that this is due to the changes in the mucous membranes. Perhaps vitamin A deficiency plays a rôle in colds, sore throats, and inflammations of the respiratory passages and the intestinal tract. Therapeutic possibilities suggest themselves here, but one cannot say any more than this at present. In rats fed on a diet deficient in vitamin A concretions form in the urinary passages [Fig. 228 (A)]. When vitamin A is added to the diet these " stones " disappear (B). During the winter months, because of a lack of food rich in carotin, the body is relatively deficient in vitamin A.

Cod-Liver Oil. The human body needs at least $\frac{1}{1000}$ gramme of carotin daily, but the optimum quantity is about $\frac{1}{200}$ gramme. Milk, butter, eggs, carrots, string beans, cucum-

bers, tomatoes, and liver are all rich in carotin. During the summer the liver contains four times as much vitamin A as during the winter, because animals have fresh food. Vitamin A is present in very large quantities in fish livers. The livers of such fish as cod and halibut are used to procure the oils containing vitamin A. Cod-liver oil contains five times as much vitamin A as the best, fresh liver of a land animal, and ten times as much as the best butter.

Vitamin B. Vitamin B is the most widely distributed of all vitamins, being present in all natural foods. Brewer's yeast contains an abundance of vitamin B, and where beer is consumed daily there is no B-avitaminosis.

Related Vitamins

Research in this subject has shown that vitamin B is a member of a large group of substances known as the vitamin B complex. Within this group vitamin B has been designated as B_1. Three members of this large group (B_1, nicotinic acid, and riboflavin) have been shown to be chemical entities and have been unequivocally linked with deficiency disease in man. Vitamin B_1 is essential in normal human metabolism as well as in lower forms of plant and animal life. It is present in abundance in wheat, rice, peas, beans, and lentils. Vitamin B_1 is contained in whole-wheat bread and in rye bread, but not in white bread because it is lost in the process of grinding and refining the flour [Fig. 226]. If animals are fed exclusively on white wheat flour, they die after 12 to 40 days. If they receive rye flour, they remain healthy. When rice is polished, the skin and the embryo are removed, and with them the vitamin content. Polished rice is devoid of vitamins.

Beri-Beri. In eastern Asia where polished rice is the chief food of large masses of the population, the exclusive use of this food produces a disease known as beri-beri. The direct cause of beri-beri is a deficiency of vitamin B_1 which produces a disturbance of metabolism in the body. This disease is characterized by inflammation of the nerves, degeneration of the nervous system, accumulation of body fluid in the tissues and body cavities, and enlargement of the heart, leading eventually to heart failure and sudden death.

Vitamin B Deficiency and Its Treatment. Mild forms of beri-beri appear among children fed exclusively on milk and carbohydrate foods among pregnant and nursing women (since the child derives its vitamin B_1 from that ingested by the mother) and in persons with heightened metabolism. In those cases where the metabolism of the body is increased by strong muscular exercise, fever, or the administration of thyroid tissue, the vitamin intake must likewise be increased, otherwise the individual suffers a loss of appetite with a consequent loss of weight.

Varying Seasonal Needs

In normal conditions an adult requires from one to two milligrammes of pure vitamin B_1 daily. This requirement is not fixed, however, but varies with the body weight and stature of the individual, with his occupation, and also with the season of the year. A greater vitamin intake is required in winter than in summer, just as a person performing heavy labour also has a higher requirement. There is no disease that can be cured as rapidly as the paralysis

due to vitamin B_1 deficiency. A pigeon, unable to move for days owing to beri-beri paralysis caused by a diet of polished rice, is able to fly away a few hours after a lump of yeast has been administered.

Vitamin C. Vitamin C is an acid, which has been named ascorbic acid to denote its anti-scorbutic (scurvy-preventing) nature. In contrast to vitamin B_1, it is found not in the plant embryo but in fully developed plants. All actively growing parts of the higher plants (roots, stems, buds, and pods) as well as all fresh green leaves contain significant quantities of vitamin C. Almost all mammals synthesize their own ascorbic acid in the liver and are consequently not affected by a deficiency of vitamin C. Only man, the anthropoid apes, and guinea pigs do not have the ability to synthesize ascorbic acid. The distribution of vitamin C in the human body is similar to that in the guinea pig and in animals such as the rat and the chicken which synthesize their own supply of vitamin C. In general the tissues that are characterized by a high metabolic activity have a high vitamin C content.

Vitamin C Deficiency

An important centre for storing vitamin C is the adrenal cortex [Fig. 229 (a)]. If the body is deficient in vitamin C, the blood vessels become fragile and bleed easily. Black and blue marks appear on the skin (c) and near the eyes (d), the gums bleed easily (e), the hormones and enzymes function poorly (b), carbohydrate metabolism is disturbed, resistance to bacterial infection is lowered, and inflammations of the respiratory passages develop (f). The body requirements for vitamin C vary for different age groups. Infants need from about 8 milligrammes (for newborn babies) to 50 milligrammes daily; children require from 22 to 100 milligrammes or even more; and adults from 28 to 100 milligrammes or more. If the body is deficient in vitamin C, an avitaminosis appears which may take one of three different forms.

Scourge of the Sea

Sea Scurvy. The most serious form is sea scurvy, a disease feared by all seamen in former centuries. It appears when people must live for long periods on preserved meats and canned foods and are unable to obtain fresh vegetables and fruits. The individual loses his appetite, becomes weak, and bleeds from the mouth, nose, intestine, and urinary bladder. The blood which leaks out of the surface blood vessels forms dark spots (petechiæ) and nodules that break open and spread a foul odour. The heart fails, and death ensues.

It was recognized very early that scurvy can be prevented by the use of certain foodstuffs. Captain Cook on his voyages round the world provided preserved cabbage for his men. The French explorer Cartier learned from the American Indians how to cure scurvy with a decoction of the sprouts of the Canadian fir. In 1795 the British Navy introduced the use of lemon juice to prevent scurvy.

Infantile Scurvy. Infants particularly need a great deal of vitamin C. During pregnancy the mother supplies the child with the vitamin. At birth the child is supplied with reserves sufficient for a few days, the quantity furnished depending on the state of nutrition of the mother. Thereafter vitamin C must be supplied either through breast milk or as a supplement to artificial feeding in order to maintain the infant's supply

at the blood level required by the body. Breast milk has long been considered much richer than cow's milk in vitamin C, and chemical tests have confirmed this. If a child is fed on cow's milk without any supplementary administration of vitamin C, it will very likely develop scurvy. This can easily be prevented by adding fruit juices—for instance, orange juice—and fresh vegetables to the child's diet.

Spring Sickness. If the body does not receive enough vitamin C during the winter due to a scarcity of fresh fruits and vegetables, the individual may develop a latent avitaminosis. Such a person complains of fatigue, inability to work, weakness of the legs, headache, and bleeding gums, and is very susceptible to various infections. This condition occurs particularly in the spring and has therefore been called "spring sickness." These symptoms of mild scurvy appear particularly among children during the first months of spring. This condition is easily overcome by the administration of vitamin C.

Vitamin C occurs in rose hips, pine needles, and lettuce, and in citrus fruits, such as lemons, oranges, and

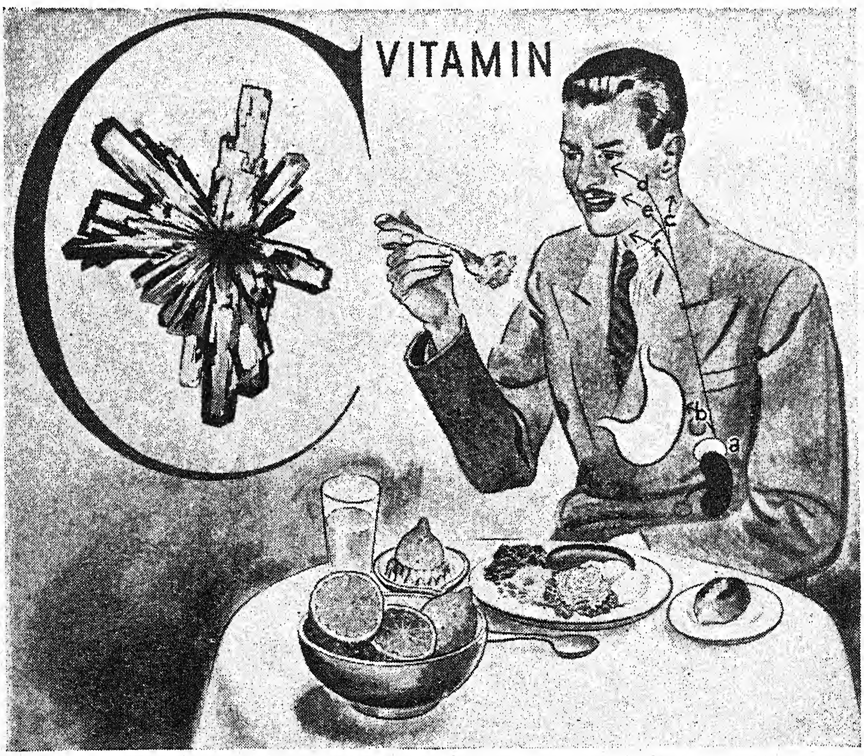


FIG. 229. *Vitamin C. Within the letter C is shown the beautiful crystal of this vitamin, which is found in green vegetables, lettuce, potatoes, and citrus fruits such as lemons, oranges and limes. Vitamin C is stored in the adrenal cortex (a) and passes thence to the stomach (b), skin (c), mucous membranes (d), gums (e), and respiratory passages (f). Lack of vitamin C causes severe disorders, such as scurvy,*

grape-fruit. It is also abundantly present in parsley, radishes, tomatoes, blood, liver, and fresh meat. The vitamin C content of the potato is not high, but since it is consumed in large quantities in various European countries, it furnishes an important source of vitamin C for large communities.

Abolishing Scurvy

In the Scandinavian countries scurvy has disappeared since the introduction of the potato. Thus under normal conditions ordinary foods can usually be relied upon to supply this essential factor. For therapeutic use in cases of disease synthetic preparations of crystalline vitamin C are now available. Ascorbic acid may be administered orally in tablet form or parenterally, by injection into muscles or veins.

The Ultra-Violet Rays. The sun radiates waves of varying length. Vibrations between 3,888 and 6,500 Angström units are perceived by us as light (an Angström unit equals one ten-millionth of a millimetre). Shorter and longer vibrations are invisible. The shortest visible waves are those of violet light rays. Beyond them are still shorter vibrations that we are unable to perceive, which are therefore known as ultra-violet rays.

Sunlight in the Skin

The shorter the wave length, the less its penetrating power and the more are the rays arrested in the skin, where they excite irritation. The ultra-violet rays produce the most irritation, causing the condition known as sunburn. In addition to this effect ultra-violet rays also exert a photochemical action on certain fats in the skin.

Vitamin D. The skin contains a fat known as cholesterol. Closely related to cholesterol and constantly associated with it is another compound known as ergosterol. This is the inactive form of vitamin D. Ergosterol has the capacity for absorbing certain ultra-violet radiations, particularly those at wave lengths of 260, 270, 282, and 293 millimicrons. (A micron [μ] is equivalent to 0.001 millimetre, and is another unit used for the measurement of wave lengths.) When ergosterol is exposed to ultra-violet radiations of these wave lengths, it is transformed into vitamin D [Fig. 230 (6)]. Vitamin D is also formed by irradiating ergosterol outside of the body —for example, by placing milk containing ergosterol in front of an ultra-violet lamp. By irradiating ergosterol vitamin D can be prepared in any quantity desired (9 and 10).

Bone-forming Vitamin

The human body requires extremely small quantities of vitamin D. The calcium metabolism of the body is controlled by vitamin D. Bone consists of calcium phosphate. Vitamin D is present in the blood and acts by increasing the absorption of calcium and phosphorus from the intestine, by increasing the solubility of these minerals in the blood, and by conserving them in the body. Thus vitamin D aids in the calcification of bone and the formation of calcium phosphate (8). When the vitamin is absent or deficient in the diet, calcification of bone is interfered with and rickets results.

Rickets. In this disease the bones remain soft and become bent; the growth zone between the shaft of the bone and the joint cartilage thickens and gives rise to nodules at the wrists, ribs, knees, and ankles. The bones of the skull also thicken at certain

points, giving the head a square box-like form. The muscles are flabby and the abdomen is prominent ("pot-bellied") on account of enlargement of the liver and intestinal flatulence. Under the weight of the trunk the spine bends backward or laterally. The normal process of dentition is disturbed. Late teething is a characteristic feature of rickets, and the teeth that appear may be small and badly formed.

Rickets and Sunshine. Rickets is much commoner during the winter than the summer months, as well as in countries deficient in sunshine. These seasonal and geographic differences are due to a varying absorption of ultra-violet radiation by the atmosphere at different times during the year and in different places. In winter the axis of the sun's rays is so oblique that they must travel through a greater depth of atmosphere. As a result the ultra-violet rays are mostly absorbed.

Sunlight Starvation

In those large cities where the atmosphere is contaminated by smoke and dust particles the degree of absorption is even greater. Ultra-violet radiation is also lost when sunlight passes through window glass since the lead in the glass absorbs the rays. Moreover, large groups of people—for example, miners, night workers, and indoor workers in general—are unable to take advantage of sunlight because of their occupations. Since a large part of the vitamin D in the body is created through the activation of ergosterol in the skin by ultra-violet rays, it is obvious that large numbers of individuals in urban centres and in certain occupations will have a vitamin D deficiency during the winter months. At present, however, it is possible to obtain ultra-violet radiation artificially by means of mercury vapour lamps and to administer vitamin D in highly concentrated forms. The result has been that serious forms of rickets in children have become relatively infrequent. At the same time it would undoubtedly be of benefit if vitamin D was taken by both adults and children during the winter months. It is not unlikely that the general level of health throughout the population would be raised.

Arctic Elixir

Cod-Liver Oil. For some as yet unknown reasons the bacilli and algæ of the Arctic seas are particularly rich in ergosterol [Fig. 230 (1)]. They serve as food for crabs and snails, which are themselves eaten by small fishes, and these in turn are the prey of codfish (2). The cod stores vitamin D in its liver, and it is from this organ that cod-liver oil is expressed (3). Since ancient times cod-liver oil has correctly been regarded as a truly magic remedy for all the developmental disturbances of the child. Recently it has been possible to prepare fish oils of such great concentration that several drops a day are sufficient to correct any vitamin D deficiency (4). Besides the liver of the cod, considerable quantities of vitamin D are also contained in mackerel, herring, egg yolk, butter, and animal livers.

Safeguard in Pregnancy

During pregnancy the child receives its vitamin D from its mother. For this reason the vitamin D requirements of the maternal body at this time are greater. If the needed extra vitamin is not supplied, the teeth decay or become loose, the bones become softer, and disorders

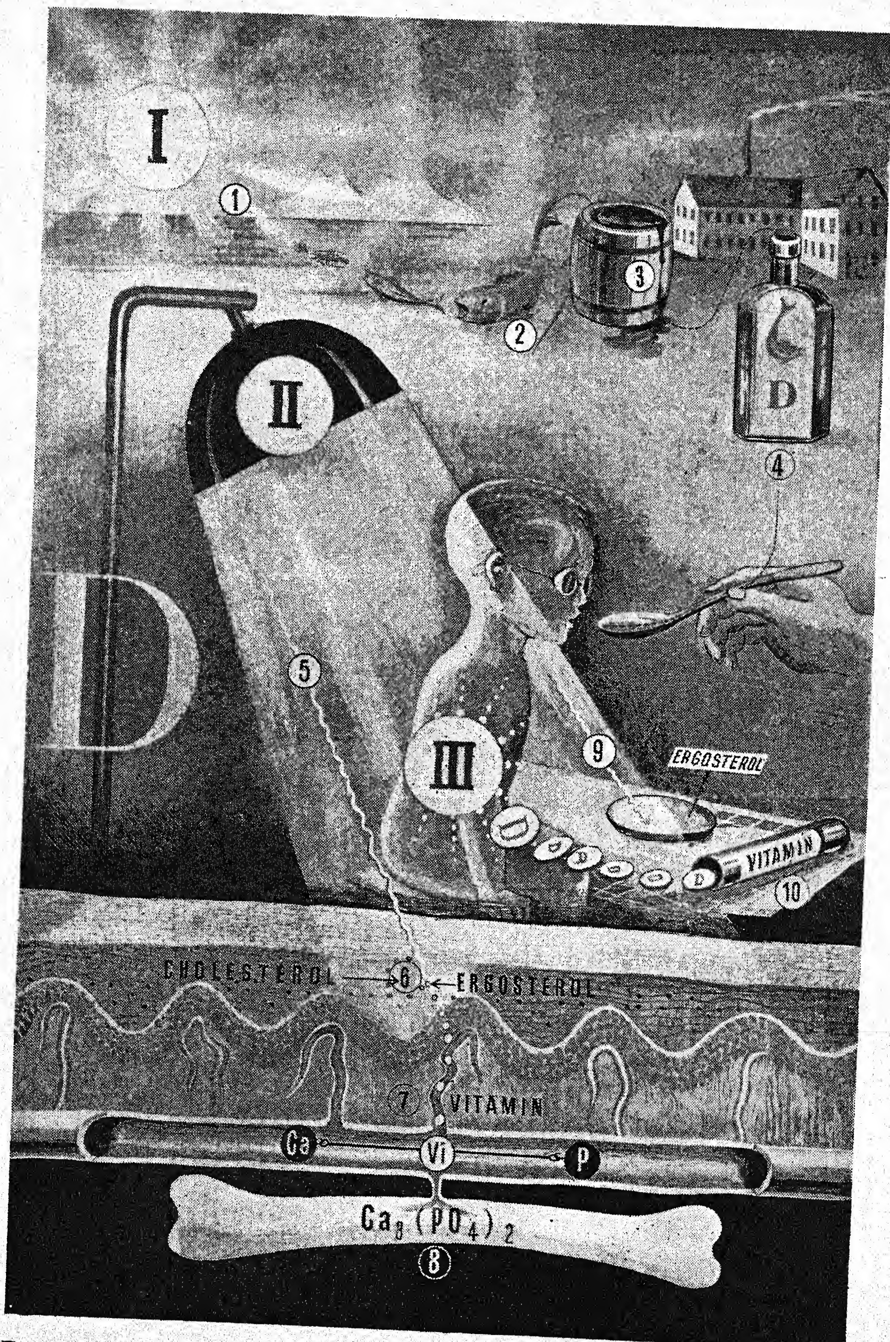


FIG. 230. *Vitamin D and its function in the prevention of rickets (Pages 324-327).*

of both appetite and digestion appear. It is therefore a sound policy to administer vitamin D in adequate quantities to all pregnant or nursing women, no matter what their diet or the season of the year. The vitamin may be administered either by mouth or by irradiating the skin. If a nursing mother receives ultra-violet treatments, the vitamin D content of her milk increases, and her child is benefited. Ultra-violet irradiation of a nursing mother has the same effect as the administration of vitamin D to the child.

The Treatment of Rickets. There are three chief methods for the treatment of rickets [Fig. 230]:

I. The administration of cod-liver oil. Metaphorically speaking, cod-liver oil is fluid light, the captive ultra-violet light of the northern seas, Polar light poured into bottles and administered with a spoon (1-4).

II. After the discovery of ultra-violet radiation and its relation to vitamin D, lamps were constructed which were able to produce ultra-violet rays. Since active rays of ultra-violet light could be obtained whenever needed from such artificial sources, these lamps were soon employed for therapeutic purposes. A child with vitamin D deficiency is placed under such a lamp and exposed to the rays for specific periods.

How Light Rays Build Bone

The rays activate ergosterol in the skin and transform it into vitamin D, which in turn acts on the calcium and phosphorus in the blood, combining them to form calcium phosphate (5-8).

III. Later it was discovered that vitamin D is also formed outside the body when substances containing ergosterol are irradiated by means of ultra-violet lamps. Thus it became unnecessary in a great many cases to expose the child itself to ultra-violet rays. Instead ergosterol was irradiated and administered by mouth, thus offering a more economical and simpler method of treatment (9-10).

Selecting a Remedy

While this is an important advance in vitamin D therapy, yet one should not jump to the conclusion that the other forms of therapy mentioned above (I and II) are thereby completely superseded. Each of these three methods has its particular advantages, and an experienced physician will know which method or which combination of methods to use in a particular case. For this reason laymen should not practise self-medication when they suspect a deficiency of vitamin D, but should consult a physician, who will determine whether such a condition exists and advise them regarding the most appropriate form of therapy.

The Danger of Excessive Doses of Vitamin D. The use of irradiated ergosterol or vitamin D in large doses should occur only under the supervision of a physician since this vitamin is not entirely innocuous. Overdosage produces such subjective symptoms as intense headache, nausea, vomiting, profuse perspiration, loss of appetite, and lassitude. Excessive doses of vitamin D increase the blood level of calcium and phosphorus, and may produce calcification in the kidneys and the blood vessels. For this reason vitamin D should not be used in large doses without consulting a physician.

Vitamin E. Vitamin E is found in growing plants and is abundantly present in the wheat germ, in lettuce, tomatoes, meat, and others foods.

The operation of vitamin E in the human body is not yet completely understood. In animals it has been proved that vitamin E is necessary for normal reproduction.

The Fertility Vitamin

Of animals reared on diets lacking vitamin E the males become sterile, while the females that are fertilized fail to carry their young to term. Wheat-germ oil containing vitamin E has been used in the treatment of habitual miscarriage in women with some success.

Riboflavin. Riboflavin was first isolated from milk and was originally called lactoflavin. It has also been named vitamin B_2 and vitamin G. It is a yellow substance with a characteristic fluorescence and was first synthesized in 1935. In the body, the liver, kidney, and heart contain the largest amounts of this material. The body guards its store of riboflavin very carefully. Rats will die for lack of riboflavin, but the liver, kidney, and heart still contain about one third of their normal quantity. Its essential function is not yet entirely established, but there is no doubt that it plays an important part in the oxidative processes of the cells.

Pellagra

P-P Factor (Pellagra-preventive Factor). Pellagra is a disease found in regions and countries, such as Italy and the southern United States, where corn or maize forms the chief dietary staple of the poorer classes in rural districts. However, it is not confined only to these regions. The disease is characterized by symmetrical pigmentation of the skin, particularly the exposed parts such as the face and hands, gastro-intestinal disturbances, and nervous and mental disorders. While classic, full-blown cases of pellagra are relatively uncommon outside the southern United States, mild forms of the disease are quite frequent, particularly among individuals suffering from gastro-intestinal diseases or gall-bladder conditions. In such persons the development of pellagra is due to a failure to consume a diet quantitatively or qualitatively adequate. In many instances this failure arises from long-established faulty dietary habits, arbitrary diets for the relief of gastric symptoms such as dyspepsia, and long adherence to unbalanced diets employed for the treatment of diseases such as peptic ulcer, chronic colitis, or diabetes.

Nicotinic Acid

In 1937 it was discovered that "black tongue," a disease of dogs, analogous to pellagra, could be cured by the administration of nicotinic acid. Since then it has been successfully employed in the treatment of pellagra. It had been known for a number of years that pellagra could be cured by a diet of yeast and fresh meat, including liver and kidney, and it had been assumed that such foods contained a pellagra-preventive factor. Now it appears that nicotinic acid is either the P-P factor, or a compound that combines with other substances to form the vitamin.

Vitamin T. Vitamin T is a substance found in egg yolk and sesame oil, which, when ingested by human beings or by rats, increases the number of platelets in the blood. No other information about this vitamin with regard to either its nature or physiological action is as yet available.

Vitamin H. In 1926 two American scientists, while studying the P-P

factor of pellagra, observed an inflammation of the skin in rats which was produced when they attempted to demonstrate experimentally a deficiency of the P-P factor in these animals. Later studies showed that this skin disturbance is not due to a deficiency of the P-P factor but of some other substance. It was proposed that this factor be called B_6.

Obscure Vitamins

More recently it has been named vitamin H. It is present in liver, yeast, fish muscle, rice bran, and wheat germ. Until now this dietary factor has been found essential only for the nutrition and growth of rats.

Vitamin K. Vitamin K is a specific vitamin the absence of which in the diet of chickens, young birds, pigs and rabbits causes the blood to become slow in clotting. This vitamin is present in pig's liver, spinach, cabbage, tomatoes, and alfalfa. Little is known of the chemical nature of this dietary factor. It appears that the normal human body obtains vitamin K directly from ingested food, or in consequence of the putrefactive action of intestinal bacteria on food.

Aiding the Surgeon

Inasmuch as this vitamin prevents bleeding in animals it has recently been administered to persons with jaundice who must be operated on, in order to prevent bleeding. Jaundice disturbs the normal clotting of the blood and renders such individuals liable to hæmorrhage during and after an operation.

Vitamin P. Closely related to vitamin C is a substance found in lemons, red peppers, and tea, which has been labelled vitamin P. It is believed that this factor helps the body to retain vitamin C. At present little is known about its action in the body.

The Vitamins and the Organism. The discovery of the vitamins and the rôle which they play in the economy of the living organism is one of the great achievements of the modern science of nutrition. The study of vitamins is constantly progressing along various lines of investigation. Factors are being isolated, their chemical nature studied, their synthetic preparation attempted and carried out, their physiological properties analysed. And as a result of these various activities the relation of the vitamins to the fundamental biologic processes of the body becomes clearer, and even now it is known that certain vitamins are concerned with tissue and cell respiration, the permeability of the capillary blood vessels, and other bodily functions.

Variety in Food

The reader will probably be impressed by the important role played by the vitamins in the body, and wonder whether extra quantities of vitamins may not be necessary in his particular case. In general an extra supply of any vitamin is unnecessary if the individual has a well-rounded diet containing fresh meats and vegetables. A diet containing milk, butter, cheese, eggs, tomatoes, carrots, lettuce, young radishes, chives, potatoes, cabbage, spinach, lemons, oranges, apples, berries, bananas, fresh meat, kidney, liver, brain, and rye bread will contain all the necessary vitamins. The average person has no need for any special expensive vitamin preparations in tablet or fluid form. Should there be any doubt on this point, the individual should consult his physician first before attempting to treat a condition which, after all, may be non-existent.

THE MORNING CUP OF COFFEE

FIG. 231. *The effect of coffee upon the human system varies considerably at different hours of the day. Morning coffee acts upon the circulation; the blood-pressure rises, the work of the heart is increased, while the kidneys remove waste products from the body.*

CHAPTER XXIX

Hunger and Thirst; Stimulants

METABOLIC EQUILIBRIUM. THIRST. HUNGER. WHAT ARE STIMULANTS? WHAT IS POISON? COFFEE. TEA. TOBACCO. NICOTINE. ALCOHOL. THE RELAXATION OF INHIBITIONS. PROHIBITED AND PERMITTED. IS ALCOHOL HARMFUL?

ONE of the most characteristic phenomena of living things is metabolic equilibrium. Each organism grows to a certain point, and stops when it is fully developed, maintaining its weight through all the subsequent phases and vicissitudes of its life. This state is described as metabolic equilibrium.

Control of Body Weight

Abnormal measures such as fattening or reducing diets must be used to make the body change its weight, but in most cases it generally returns to its old state of equilibrium after such a diet has been abandoned. The regulation of body weight is performed by thirst, hunger, and also by appetite.

Thirst. Among the various metabolic centres in the brain, there is also a hunger and thirst centre. In Figure 232 we see three people: a man behind a counter, and before him two men, one reaching for some food, the other for a drink. In the sandwiches are black crosses symbolizing food, and in the glass white dots symbolizing water. The blood of the man behind the counter contains the symbols of both water and food. He lacks nothing; he is satisfied. The blood of the man at the right lacks water. His brain has a nervous apparatus, the thirst centre, which is regulated and adapted to a certain water and salt content of the tissues. If this level changes, by either rising or falling, the centre is stimulated and sends an impulse to the pharynx, which contracts. It is this contraction of the pharynx that we feel as a " dry throat " or as thirst. If the body loses too much water due to excessive perspiration or diarrhœa, the blood withdraws water from the tissues in order to maintain its composition constant. This removal from the tissues registers in the thirst centre and is called to our attention as a dry throat.

" Braking " the Organs

Hunger. The man on the left side has enough water in his blood vessels, but he lacks food. This lack of nutritive materials is noted by a centre in the brain, called the " hunger " centre. This hunger centre is a brake mechanism. It brakes the activities of the stomach and intestine as long as the blood contains sufficient food. If the blood becomes deficient in nutritive materials, the inhibitory effect is relaxed, and the intestines

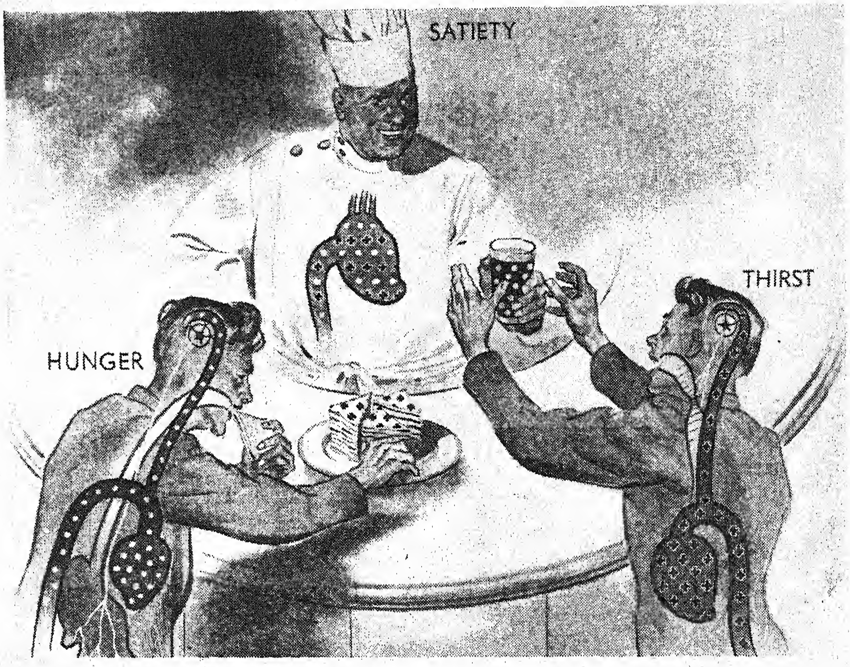


FIG. 232. *The man on the left is hungry—the hunger centre in his brain urges him to eat. The man on the right is thirsty—his thirst centre craves liquid. But the barman requires neither food nor drink; he is satiated and his hunger and thirst centres are quiescent. Black crosses symbolize food; white dots indicate water.*

become active—one can hear the rumbling of a hungry stomach.

Hunger has nothing to do with an empty stomach, as most people believe. A newborn infant comes into the world with an empty stomach; nevertheless it is not hungry for several days, since its blood was enriched with nutritive materials by the mother before birth. A feverish patient is not hungry, because the body uses up its protein supplies, thus feeding itself from within. Hunger disappears when the blood is filled with nutritive materials.

Appetite. A feeling of hunger informs us that the blood lacks nutritive materials. Hunger is not particular; the body cries for any kind of fuel (bread, potatoes, vegetables). Our appetite sees to it that we choose a mixed diet as required by the metabolism of the body. If a heap of barley is placed before a chicken, it eats with a great deal of appetite, and then stops. Is the chicken satisfied? No. It has only been satiated with barley. If corn granules are now strewn in front of it, the "satisfied" chicken once again begins to eat with appetite. When it stops eating corn, it can then be fed anew with bread, or other food, until it is ready to burst. Man behaves similarly. When he has had enough soup, he eats meat and vegetables; and when he has had enough of these, he passes with pleasure to a dessert, then to fruit, and finally he has cake and coffee. At the same time, he would object

strenuously to eating this same quantity of food in the form of potatoes.

How Long Can an Individual Go Hungry? The ability to starve depends on the organization of the animal species. A tick lives on a bush and waits until some animal approaches. It then falls on the animal and attaches itself firmly to the skin of its victim. Sometimes it takes years before a suitable host animal passes. Warm-blooded animals have a more active metabolism, and consequently consume their stores rapidly. The smaller and more active the animal, the more rapidly does it use up its food supplies. A song bird starves to death in five days and a dog in twenty. In general a warm-blooded creature dies when it has lost half its normal weight. Because of a conspiracy Count Ugolino, together with his sons, was condemned to death by starvation. The children died in the inverse order of their ages, the youngest first and the oldest last. The father survived them all and died on the eighth day. The more calmly an individual maintains himself, both inwardly and outwardly, the longer will the protein stores of the body last. Excitement and fear consume the body rapidly and hasten the occurrence of death.

Food Animates the Nerves

What are Stimulants? Stimulants are substances that are ingested not because of their nutritive properties but because they exert certain desired effects on the nervous system. All foods act on the nervous system. If one eats a piece of bread, part of it is transformed into alcohol, which circulates in the blood and stimulates the brain. Pepper, salt, mustard, cinnamon, and the spice substances of parsley and chives are stimulants. A pickled herring and a sharp cheese are stimulants even more than they are foods. It is just as difficult to draw any sharp line of demarcation between foods and stimulants as between poisons and non-poisons.

What is Poison? The concept of poison does not exist in nature. Morphine is no poison. A goat eats twenty grammes of morphine and continues to jump around without any apparent ill effects. A rabbit chews belladonna with pleasure and without the slightest poisonous effect.

"Poison"—A Relative Term

Hydrochloric acid, too, is not a poison when the stomach produces it constantly without any harmful effect on the body. In biology it is not easy to define precisely the concept "poison" and to point out what is harmful and what useful. It is *impossible* to give such a definition in one sentence for experience has shown that:

1. The concept of a poison depends on the species of animal. Substances that are innocuous for goats are poisonous for man, and vice versa.

2. The concept of poison depends on the individual ingesting the substance. For the father in the easy-chair a cigar is not poisonous; for the three-year-old at his feet it is fatal.

3. The concept of poison depends on habituation. If the father in the easy-chair smokes daily, he is not affected by a cigar. If he were a non-smoker, however, it would act as a poison.

4. The concept of poison depends on the quantity ingested. There is a tolerance limit for every substance,

up to which it has no poisonous effect, and beyond which it acts as a poison. In the quantity in which it circulates in the blood, potassium cyanide is not poisonous. On the other hand, water can act as a poison if five quarts are poured at one time into the stomach of a human being, an ancient form of torture.

The Time Factor

5. The concept of a poison depends on the element of time. A heavy cigar smoked in the morning on an empty stomach is ten times more "poisonous" than the same cigar after the noonday meal.

6. The concept of a poison depends on admixtures. The caffein in coffee has a different effect from the same quantity of caffein in tea, because in each case the caffein is coupled with different substances. Similarly, alcohol in absinthe acts differently from the same quantity of alcohol in a mild wine.

These six principles may be expanded, but they suffice to show that "poison" is non-existent in nature in the sense in which the word is employed by human beings.

Coffee. The roasted coffee bean is a chest full of precious treasures. Science has not yet succeeded in discovering all its components. The best-known of these is caffein, a substance chemically related to uric acid. Caffein is not found in a free state, but combined with acids. The bean contains one per cent caffein, but the effects produced by drinking coffee are not due entirely to caffein.

Early Views on Coffee

The introduction of coffee into Europe during the latter part of the seventeenth century soon led to spirited controversies for and against its use. Certain "savants" proved clearly that coffee was a poison.

Coffee may be a poison for laboratory animals when given in large doses for long periods. It may also produce toxic effects in small children. For adults, however, if consumption is kept within bounds, coffee is not a poison, particularly in the case of habitual coffee-drinkers. Nervous individuals who are apt to be injured by coffee are those most likely to exceed these bounds. The bad effects are usually not very serious and generally disappear quite promptly if the habit is discontinued. The symptoms produced by excessive consumption of coffee are nervousness, palpitation of the heart, headache, insomnia, and digestive disturbances.

General Effects of Coffee

1. Coffee has a pleasant taste, thus affording pleasure to the senses like music or flowers, apart from any other effects.

2. By means of its odour it activates the reflex apparatuses of the nose, like all agreeable odours, thus producing numerous stimulating effects in various parts of the body.

3. In the brain it dilates the vessels so that the cerebral circulation is improved and the brain freed of fatigue toxins. "Coffee is refreshing!"

4. By stimulating the nerve cells it increases mental efficiency, permits more sustained intellectual effort, and produces psychical stimulation.

5. It increases the work performed by the heart. The pulse rate increases and the amplitude of the heart-beat becomes greater because the cardiac muscle contracts more powerfully.

6. The tonus of the skeletal muscle

is increased, like that of cardiac muscle.

7. The movements of the intestine become more active. Coffee has a laxative action. Individuals affected with intestinal spasm or gall-stones frequently find that coffee disagrees with them, because the sensitive intestine or bile ducts contract even more under the influence of coffee.

8. The gastric glands secrete more actively. Persons suffering from excess gastric secretion are therefore likely to complain of heartburn after drinking coffee. For healthy individuals, however, such stimulation of the gastric secretion is indeed highly desirable, especially after a large meal.

9. It stimulates renal activity so that larger quantities of salts are removed from the blood.

10. A special effect of coffee is a striking intensification of the desire to converse and communicate with other people.

The Effects of Coffee at Various Times during the Day. The different effects produced by coffee at various times of the day are illustrated by Figures 231 and 233-235. In the morning [Fig. 231], coffee acts on the kidneys. In the course of the night, waste products collect in the blood, the skin glands become overloaded with substances to be excreted, and the blood vessels are at rest. Now, when an individual drinks his morning coffee, the vessels dilate, the renal filters are filled with blood, urine and perspiration are produced, and in this manner the body gets rid of a large proportion of the waste products accumulated during the night.

Coffee after lunch acts differently. Now the digestive organs are the centre of activity, so that the coffee acts on the gastro-intestinal glands and the musculature of the alimentary canal. In this way it aids the digestion of food [Fig. 233].

Afternoon coffee heightens the tonus of the musculature since the individual is quite active at this time. Everyone knows the incomparable effect which a cup of hot coffee produces on the body after a period of intense activity [Fig. 234].

Very different again is the effect of a cup of coffee taken in the even-

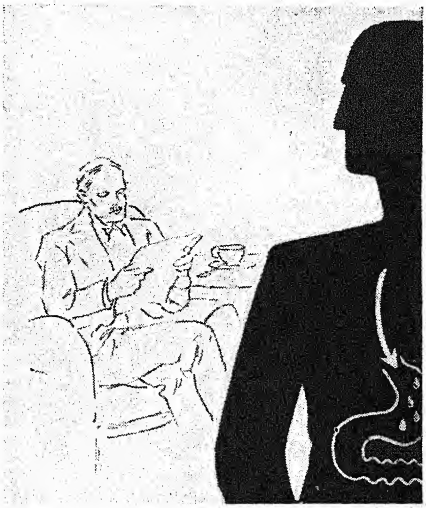


FIG. 233. *Coffee after lunch acts on the stomach and intestine, aiding digestion.*

ing in the course of some intellectual activity. At this time the coffee does not act on the tonus of the musculature. Instead it produces a quicker and clearer flow of thought, increases the vividness of the imagination, enables one to appreciate sensory impressions more clearly, and also permits a better association of ideas [Fig. 235]. These four cups of coffee that are consumed in the course of a day (morning, noon, afternoon, evening) are the same chemically, but

FIG. 234. *Afternoon coffee increases the tonus of muscles that are active at this time.*

differ greatly in their biological effects.

Black Coffee and Café au Lait. Milk is a colloidal suspension—that is, it contains microscopic fat globules as well as protein particles in suspension. Coffee has a similar composition. It contains in suspension drops of ethereal oils, as well as various large protein molecules and other complex compounds. If coffee is mixed with milk the colloidal systems are disturbed. The caffein of the coffee combines with the protein of milk, with the result that its action is weakened. Adding milk weakens the effect of coffee; it may be regarded as a partial decaffeinization.

Tea. It is well known that tea does not produce the same effects as coffee, and that it is by no means as strong. All the more surprising and at the same time instructive is the fact that a cup of medium strong tea contains as much caffein as a cup of coffee. As this example shows, the quantity of a stimulant is not as significant as the manner in which it is combined biologically with other substances. One gramme of caffein is one gramme of caffein—in the laboratory. In foodstuffs and in the living body the concept of a gramme of caffein exists only when it is administered in a pure state as a medicament. The quantity of tea consumed by Western man is by no means insignificant. However, he regards it not so much as a stimulant, but rather as a warm, pleasant-tasting beverage.

Tobacco. When Columbus sent his companion Miguel de Torre to explore the interior of the newly discovered country, the latter returned with the report that he had seen brown men who sat before burning pieces of wood upon which they placed dried leaves and then inhaled the smoke through tubes inserted in their nostrils. This was the first acquaintance of a European with smoking. Today there are approximately as many tobacconists as bakeries, and more money is spent on tobacco than on bread.

Deadly Poison

Nicotine. The chief constituent of tobacco is an extremely powerful poison. One cigar contains enough nicotine to kill two men—if it were injected directly into the circulation [Fig. 236].

The "Hellish Gas Mixture." Besides nicotine, tobacco smoke contains several other extremely fatal poisons, such as hydrocyanic acid ($\frac{1}{1000}$ gramme in the smoke from one cigar); 5 per cent carbon monoxide; pyridine; ammonia, which irritates the mucous membranes, causing smoker's catarrh; $\frac{1}{50}$ of one per cent of the very poisonous hydrogen

disulphide, etc. Had Miguel de Torre returned from his expedition not only with his report about smoking but also with a chemical analysis of tobacco smoke, no one would have believed him. It is in fact extremely surprising and at the same time characteristic of life that man can inhale a truly " hellish " gas mixture such as tobacco smoke for hours daily over a period of years and decades without poisoning himself; indeed, he may feel himself strengthened and so happy that, like Lessing, he would not " change places with the gods."

Avoiding Ill-effects

Heavy and Mild Tobaccos. The shorter the path from the point of combustion to the mouth, the greater will be the amount of nicotine entering the body. For this reason long, thin cigars and cigarettes are milder than short, fat ones; and a cigar will become " heavier " as it is consumed. In the first place, the path taken by the smoke grows shorter, and secondly, as more smoke is inhaled through the tobacco, its nicotine content grows greater. Therefore anyone who wishes to protect himself against the injurious effects of nicotine should not smoke a cigar or cigarette to the very end. Nor should he relight a dead cigar, for as experience shows it does not burn so well the second time and the smoke is more poisonous. One who is learning to smoke should never be permitted to start on a cigar or cigarette butt, but should be given a fresh one. Heavy cigars or cigarettes are not those with a high nicotine content, but rather those from which more than 15 per cent of their nicotine enters the body. Mild varieties are those in which under 10 per cent enters the body. The quantity of nicotine that passes into the body varies. The drier the tobacco and the greater the heat, the less nicotine will escape destruction. For this reason moist tobacco, especially in cigars, produces severer effects. This also explains why a cigar that burns well is " lighter " than one that draws poorly. One who smokes rapidly aspirates less nicotine than one who, in a manner of speaking, distils the tobacco leaves slowly and completely. In cigarette-smoking where inhalation is commonly practised, twice as much nicotine will be absorbed as a result of nasal inhalation, and four times as much in pulmonary aspiration, as in simple oral inhalation [Fig. 237].

Why Does Tobacco Spoil the Appetite? A not inconsiderable quantity of nicotine passes into the stomach with the saliva, where it inhibits the production of gastric juice.

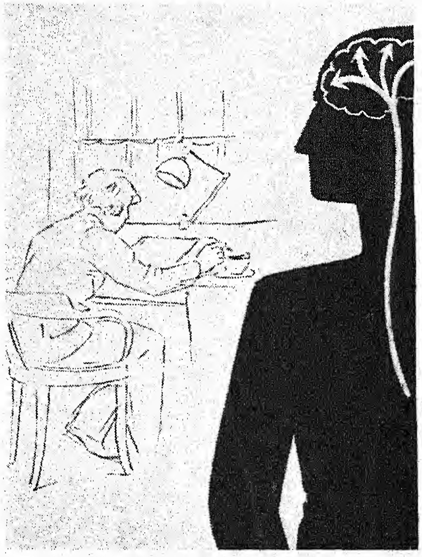


FIG. 235. *After the mechanical functions of the body have slowed down, evening coffee excites the imagination, increases sociability and accelerates thought.*

Byron is often cited as an example of a famous vegetarian; yet there is no mention of the fact that he is also a prime example of an individual who led a very unhygienic life. In the morning he ate nothing and drank tea, and instead of eating lunch, he chewed tobacco and spoiled his appetite, so that he often fasted until the following day.

The Effects of Nicotine. The nicotine which circulates with the blood paralyses the ganglia, or " switchboards," of the sympathetic nervous system. It stimulates production of adrenalin, the hormone of the adrenal gland, which inhibits normal intestinal movements [Fig. 238].

Nicotine in the System

Nicotine produces violent peristalsis and intestinal spasm, so that the career of a great many smokers begins with an intestinal catastrophe, and many smokers use their cigarettes as laxatives. The blood-pressure rises, and the dermal vessels contract so that people who smoke excessively often present a pallid appearance. The bile ducts contract. For this reason those who have some liver or gall-bladder affection frequently find that smoking does not agree with them. The effect of smoking on the nervous system is peculiar and has not yet been completely elucidated. In general, smoking has a reposeful, stabilizing effect on the nervous system. If used in excess it increases nervous excitability. Smoking also obscures the sensation of fatigue and stimulates imagination.

Alcohol. All peoples have observed that sweet juices ferment when allowed to stand long enough. Yeast moulds from the air fall into the fluid and decompose the sugar in it to carbonic acid and alcohol. Alcohol is also produced when bread is baked, but it evaporates with the heat. The effects of alcohol were recognized everywhere at a very early period, and most races brew alcoholic beverages. Knowledge of alcohol, the esteem with which it is regarded, and the existence of an intense desire for alcoholic beverages are extremely ancient and are found over the entire globe. After the Flood, the first act of Noah, who has been saved, is to repair his vineyard, and his joy at the cessation of the rain leads him to drink to excess. Ancient Egyptian papyri already contain wine songs: " Give me eighteen cups of wine. My insides are as dry as straw."

Alcohol in the Blood. There is no life without alcohol, since the carbohydrates starch and sugar form alcohol when decomposed. As a result alcohol enters the blood stream after every meal. Perhaps the feeling of lassitude after a meal is in part due to this fact. All together approximately one gramme of alcohol circulates in our body fluids. After the ingestion of alcohol this quantity is increased. It is possible to determine this quantity by analysis of the blood, and thus to establish whether an individual was intoxicated, for example, at the time of an automobile accident.

Seasoned Drinkers

When the body is habituated to alcohol, it is able to dispose of it more rapidly. It is because of this fact that one who is accustomed to alcohol is able to stand larger quantities. In the course of years, however, the capacity of the body to metabolize alcohol decreases. It is not uncommon for ageing drinkers to say: " I can't drink as much as I

used to drink when I was younger."

Alcohol—a Narcotic. Alcohol is a narcotic like ether and chloroform, but much weaker. A narcotic is a substance which has a special relation to the fats of the nervous system, penetrating rapidly into the nerve cells and exercising a paralysing influence on them. However, before a narcotic paralyses, it stimulates the nerve cells, creating in them a state of excitation. If one attempts to anæsthetize an individual by means of ether without the proper preparation, the subject first loses consciousness, but several moments later becomes excited, loses self-control, and indulges in incoherent talking and violent actions. As more of the narcotic is administered, this state disappears and the anæsthetic stage supervenes. Alcohol is not suitable for anæsthetic purposes because it is too weak and consequently takes too long to produce the desired anæsthetic stage. For the same reason, however, it is a stimulant. Alcoholic stimulation is a form of narcosis produced by slow ingestion of alcohol so that the stage of anæsthesia is not reached. In order to maintain this "stimulant" state as long as possible without producing unconsciousness, alcohol is not taken in a concentrated form like ether or chloroform, but rather in weak solutions with an approximate alcoholic content of 10 per cent.

The Effects of Alcohol. Every animal species and every human age group reacts differently to alcohol. The results of experiments on rabbits or white mice are of little value for an understanding of the effect of alcohol on men. Similarly laboratory experiments on human beings have only a limited value, since wine or other alcoholic beverages are not intended to be consumed in the laboratory and produce somewhat different effects there than in an animated social gathering. The most important factor is habituation. The effect of alcohol upon an habitual drinker

FIG. 236. *The nicotine contained in a single cigar would suffice to kill two men—if injected into the veins. But in smoking, only traces of nicotine enter the blood.*

is different from its effect upon someone who normally abstains from alcohol.

The Effect of Alcohol on the Mucous Membranes. The first effect of alcohol when ingested is to exert a strong stimulus on the mucous membranes of the mouth and the pharynx. This stimulus excites a vigorous secretion of the salivary and gastric glands. For this reason spicy wines with a considerable alcoholic content (15 to 30 per cent) are used as apéritifs to stimulate appetite. For the same reason one drinks cognac at the end of an especially rich or fat meal. In the stomach it dilates the vessels and produces a pleasant feeling of warmth. These normal conditions hold true for a moderate use of alcohol. In chronic alcoholics, however, the gastric mucous membrane is "corroded" and gastric secretion is diminished.

The Absorption of Alcohol. Warm alcohol solutions are rapidly absorbed. It is due to this circumstance that punch and mulled wine act so rapidly and vigorously, since in these cases the blood is suddenly flooded with large quantities of alcohol. Of the cool alcoholic beverages, red wine is absorbed most slowly, because its tannic acid prevents absorption.

Champagne and Sugar

Sugar favours absorption. For this reason liqueurs are especially "dangerous." Carbon dioxide likewise aids absorption. Champagne contains both sugar and carbon dioxide, and consequently no alcoholic beverage acts so rapidly and exerts such a stimulating effect. Because of this fact champagne is served when it is desired to have alcohol act rapidly and vigorously. It is served on happy occasions to heighten the joyous mood; at the sick-bed it is ideal as a circulatory stimulant.

The Effect of Alcohol on the Musculature. Only a certain percentage of the fuels of the muscle can be transformed into work-energy. This percentage rises after the ingestion of alcohol. Thus it is possible to "dope" human beings with alcohol in order to achieve "superhuman" performances. In general, however, athletes do not employ this method, for the short period of stimulation is followed by a secondary period of fatigue which is even greater.

Alcohol and Athletics

Yet much depends on the mode of life of the individual. In 1896, when the Olympic games were once again held after an interval of 2,386 years, the first marathon, a gruelling race that lasted three hours, was won by a Greek peasant named Spyros. His rivals ran without stopping. Yet he paused occasionally in the course of the race—to drink some sweet wine. He then overtook the others and was the first to finish the race. Unlike his rivals he was not a physical-training teacher or engineer in private life, but a wine-grower; and for a wine-grower there are other rules regarding the use of alcohol in athletic competitions than for those who abstain from alcohol.

The Effects of Alcohol on the Brain. The first psychic effect of alcohol is a feeling of stimulation. There is an increased vivacity of action and speech. The skin is reddened, the blood-pressure rises, and there is an increase in the rate of the heart and of respiration. Accompanying these phenomena is a comfortable sensation of warmth.

Investigation has shown, however, that alcohol really exerts a depres-

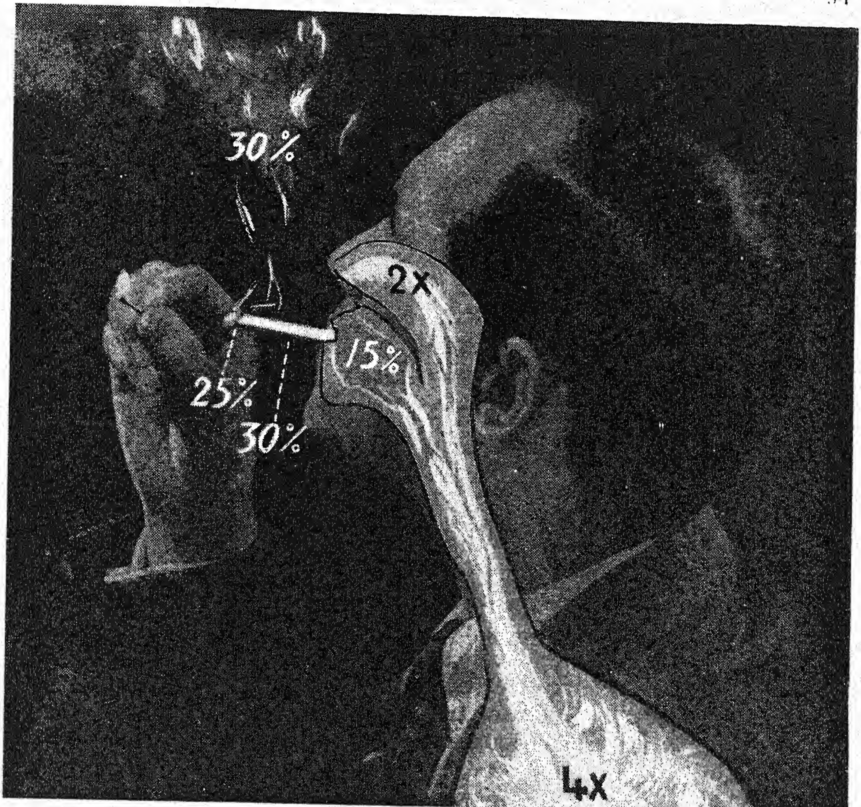


FIG. 237. *What becomes of the nicotine in a cigarette? Twenty-five per cent of it is destroyed in the area of combustion; 30 per cent remains attached to the particles of tobacco; 30 per cent escapes with the smoke; only 15 per cent enters the mouth. Of this latter fraction, only traces enter the blood, through the mucous membrane; but the amount is doubled when the smoke is breathed into the nose, and is four times as great when smoke is inhaled into the lungs.*

sing effect on the brain, certain higher functions—reflection, observation, and attention—being particularly affected. The phenomena and actions that simulate a state of stimulation do not depend on a direct stimulation of the nerve centres, but are an indirect result of reflex stimulations and paralysis of the higher function, with a resultant loss of the power to control moods.

The Relaxation of Inhibitions. Excitation is followed by paralysis. It starts with the elements of the nervous system, known as the inhibitory fibres. The inhibitory fibres are resistances that brake and regulate the stimuli in the nervous system. For the most part they are developed in the course of an individual's life as a result of education and training. The possession of inhibitory fibres differentiates a trained from an untrained individual, a disciplined adult from an undisciplined child, a scrupulous

person from someone who does not restrain his impulses and passions.

Under the influence of alcohol these controls are relaxed and the individual is no longer as critical of the world around him. His judgment is no longer so clear, and he is ready to believe things that would startle him if his mind were clear. He becomes confiding, affable, talkative, and quite ready to bridge the social gaps that separate one person from another. He makes friends and becomes very "intimate" with his environment.

Wine and Good Fellowship

Since ancient times and among all peoples wine has been used for this very reason to dissipate feelings of reserve among strangers and to create an atmosphere of fellowship. Anyone who tries to corrupt or debauch another generally tries to ply the victim with liquor—if possible, in the form of concentrated liqueurs or cognacs, which contain 40 to 60 per cent alcohol. For this reason shady deals are so frequently closed over drinks.

Prohibited and Permitted. When is the use of alcoholic beverages permissible, and when is alcohol to be avoided? Since alcohol confuses an individual's judgment, favours the appearance of mental delusions and hallucinations, and paralyses the inhibitory mechanisms of the nervous system, it has an adverse effect in all situations where clarity of thought, good judgment, and precise execution are required. Hence, for a locomotive engineer driving an express train, alcohol is a dangerous poison. An after-dinner speaker who offers a toast may drink with advantage; but a person making an attempt to drive a motor-car while intoxicated is a criminal, guilty of a crime against the occupants of the car as well as passing pedestrians.

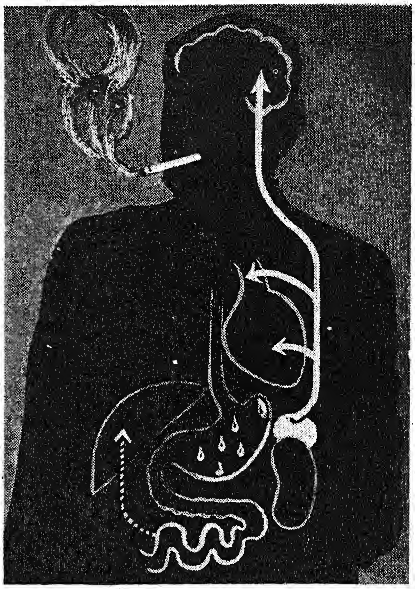


FIG. 238. *The action of nicotine is largely due to stimulation of the adrenai glands. The secretion of these glands raises the blood-pressure, increases the activity of the heart, contracts the blood vessels and inhibits normal intestinal movements.*

Is Alcohol Harmful? On the basis of centuries of experience it appears quite probable that a moderate amount of alcohol may be taken daily as part of a mixed diet without any injurious effect. In this connection it is interesting to recall that the cradle of Western civilization is the Mediterranean basin, where the consumption of wine has been extremely large for millennia. Yet nowhere on the globe has so much been accomplished for human culture as in the Mediterranean area, where Moses, Christ, Plato, Phidias, Dante, Michelangelo, Columbus, and Galileo lived and laboured for humanity.

CHAPTER XXX

Body Temperature

HEAT PRODUCTION. TEMPERATURE CENTRE. HEATING CENTRE. SHIVERING. COOLING CENTRE. PERSPIRATION. THE TEMPERATURE OF THE BLOOD. FEVER. SUNSTROKE. HEATSTROKE. COLDS. HOT AND COLD APPLICATIONS. THE FUNCTION OF CLOTHING.

OWING to the oxidation processes occurring within his body, man may be regarded as a walking furnace. He dissipates 2,500 calories daily, a quantity sufficient to heat 25 quarts of water to the boiling-point. A small ill-ventilated room containing three people becomes warm, as if there were a hot stove in it. Halls become so warm when large audiences are collected in them that people perspire.

Heat Distortion

When a person approaches the concave mirror of an astronomical telescope, the stellar picture becomes distorted owing to the heat radiated by the body. The body maintains an average temperature of 98.6° Fahrenheit for decades, unaffected by any external influences. The maintenance of this equilibrium is called the temperature regulation of the body.

The Temperature Centre. The regulation of the body temperature is performed by a centre in the brain known as the temperature centre. Actually, it consists of three centres: a control centre which regulates the temperature of the blood, and two subordinate centres, of which one raises the temperature of the blood when it drops, while the other cools the blood when its temperature is too high.

The Heating Centre. If the temperature of the blood drops, the heating centre fans the flame of the vital processes by stimulating the sympathetic nervous system. The endocrine glands secrete oxidative enzymes, the oxidation in the muscles and the liver increases and the internal temperature rises. The blood vessels of the skin contract, so that less heat is lost by radiation, the skin glands secrete a fatty material, and the hairs of the skin become erect so that a resting layer of air surrounds the body as an isolating coat [Fig. 87].

Shivering. If the temperature drops too low, the muscles are activated, and the individual shivers. Shivering is an automatic activity of skeletal muscle, initiated by the heating centre of the brain in order to produce heat.

Evaporation

The Cooling Centre. If the temperature of the blood rises, the cooling centre depresses the oxidative processes—chiefly by means of vagus stimulation—dilates the vessels of the skin in order to eliminate the excess heat of the body by radiation, and facilitates the evaporation of

perspiration. When a fluid evaporates and passes into a gaseous state it deprives its environment of heat. It is cold in the neighbourhood of waterfalls, because the dispersed water droplets evaporate and produce cold. Similarly, we feel cold after a bath, because the water which remains in contact with the warm skin evaporates rapidly. The body is constantly eliminating water through the lungs and skin. When we become warm we breathe more rapidly. Animals that do not perspire, such as the dog and the cat, extend their tongues when they are hot, and respire rapidly until they have cooled off. In addition, man is also able to perspire.

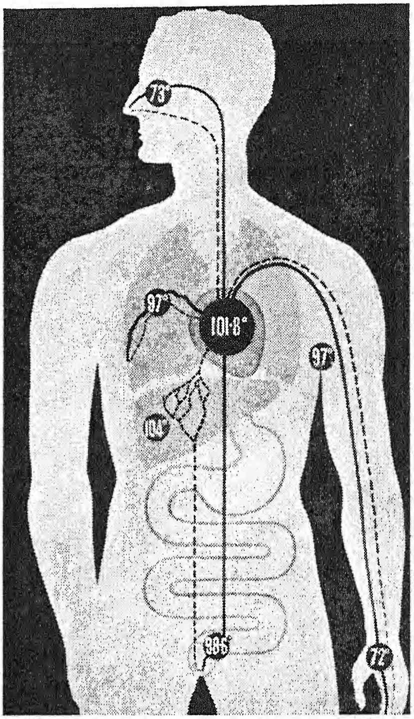


FIG. 239. *The temperature of the blood varies at different points in the circulation. It is highest in the internal organs, such as the liver, and lowest at the surface, for example, in the fingers. The temperature in the armpit is 97° F., in the rectum 98.6° F.*

Cleansing from Within

Perspiration. The sweat which emerges from the pores of the skin is a private shower which the cooling centre of the brain activates automatically when the temperature of the blood rises. Profuse perspiration is a shower which washes the body from within and not from without. It is more effective than a bathroom shower because the fluid does not flow out of fifty large openings, but rather out of millions of tiny openings in microscopic drops that evaporate rapidly. Profuse perspiration is an energetic and rapid method of cooling. A feverish individual feels greatly relieved after perspiring, while an athlete fears profuse perspiration and wraps himself in woollen robes in order to avoid the danger of rapid cooling. Most antipyretics—remedies to reduce fever—act by stimulating the centre in the brain which controls perspiration. On humid, sultry days we suffer twice as much under the heat because the evaporation of water is diminished, while a warm dry wind gives us a pleasant sensation because it facilitates the evaporation of perspiration. The use of fans and the creation of cross-ventilation are measures employed to cool the body by means of evaporation.

The Temperature of the Blood. The temperature of the blood in the heart is 101.8° Fahrenheit; in the liver and other visceral organs it rises to 104°; while in such organs as the lungs, which are in communication with the external environment, the temperature drops to 97°.

The temperature of the projecting parts of the body may be as low as 68° Fahrenheit and even lower, depending on the outer temperature [Fig. 239].

The Measurement of the Body Temperature. The temperature of the body is usually taken by placing a thermometer in the mouth, rectum, or axilla for several minutes. In the cases of children, persons who are seriously ill, and malingerers, the rectal temperature is taken.

Varying Body Heat

Morning and Evening Temperature. The body temperature of man exhibits variations of several tenths of a degree depending on the time of day at which the temperature is measured. The lowest temperature is obtained about four or five o'clock in the morning, and the highest about six or seven in the evening. These diurnal changes in temperature are probably due to the changes in the movement and tension of the muscles during the waking hours, since they are associated with parallel changes in the rate of metabolism.

When Should the Temperature Be Taken? The temperature should not be measured oftener than twice a day, except in extraordinary cases when it is taken as often as ordered by the attending physician. While taking the temperature the patient must be at rest, both physically and mentally. Although the temperature of the healthy body can be influenced only with difficulty, in sick persons and convalescents minor exciting causes are quite sufficient to raise the temperature considerably. Every hospital staff knows that on visiting days the temperatures are higher than usual. Hot compresses raise the temperature, while cold applications lower it, and they must consequently be stopped an hour before taking the temperature. The ingestion of food raises the temperature even in healthy people, so that the temperature should not be taken at meal-times.

The Temperature Curve. If one wishes to observe an individual's temperature for several days, it is expedient to chart the temperature readings in the form of a curve. This is so simple that anyone can learn to do so without any trouble, and so useful that everyone should learn how to do it. Printed temperature sheets may be obtained at the chemist's. The temperature is taken twice a day: in the morning after the patient awakes, and towards evening between five and six o'clock

Plotting the Curve

The readings are plotted on the ruled chart by means of dots, the morning temperature being entered at the beginning of the daily space and the evening reading at its close. The dots are connected by

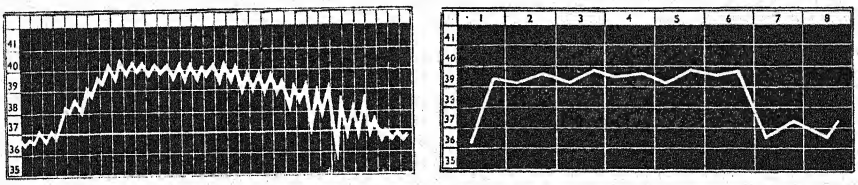


FIG. 240. *Temperature charts are maps of the course of an illness. (Left) The curve characteristic of typhoid; (Right) the curve typical of pneumonia.*

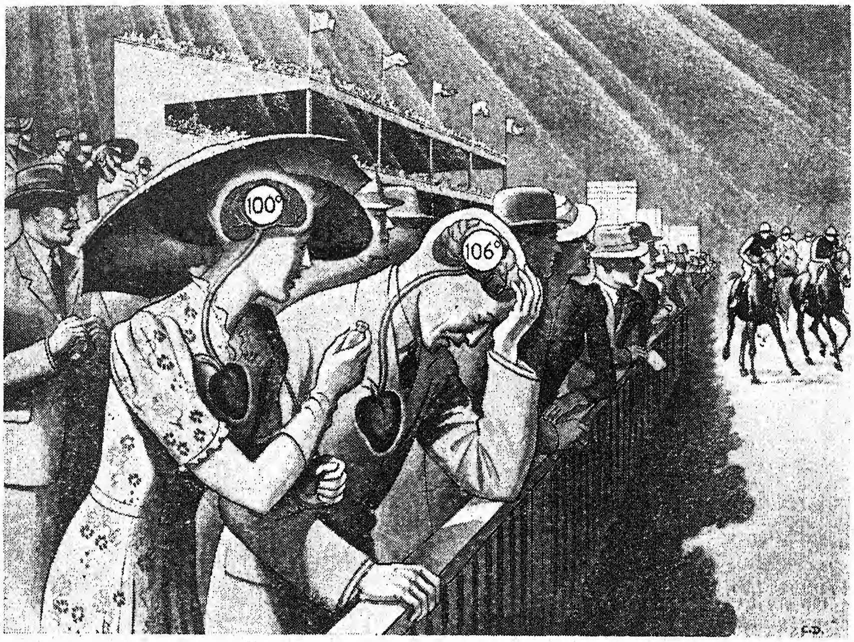


FIG. 241. *Sunstroke is caused by overheating of the brain, when the head is exposed to the strong rays of the sun. It can be avoided by shielding the head with a hat or parasol.*

lines, thus forming the temperature curve.

Fever. Many, but by no means all, diseases are accompanied by an increase of temperature, which we call fever. Fever is such a regular concomitant symptom of many diseases that the temperature is measured as soon as one suspects illness. If fever is present, one is certain that some kind of pathological process is present in the body. If no fever is present, one can with some probability exclude a number of diseases. Not only the presence of fever itself, but the course which it takes is characteristic in certain diseases. Any expert will state without hesitation that the patient whose curve is shown in Figure 240 (*Left*) has typhoid fever, while that on the right is typical of lobar pneumonia. The action on the human body of various medicaments is also reflected in the temperature curve. The significance of the temperature curve for the physician is similar to that of a weather map for the meteorologist.

Fever—a Therapeutic Reaction. We do not know what fever is. Despite numerous investigations and controversies the fever problem is not yet completely solved. Fever is probably what a physician of antiquity, Rufus of Ephesus, stated it to be, namely, a useful reaction of the body "which should not be combated. On the contrary it is such a useful therapeutic means that one might only wish that it could be produced artificially." Fever accelerates the vital processes. All the organs work vigorously. More hor-

mones, enzymes, blood cells, and wander cells are produced; the hormones and enzymes act more vigorously, and the wandering leucocytes ingest and digest harmful organisms better The circulation of the blood, respiration, and transpiration are all accelerated, thus facilitating the removal of waste products and poisons from the tissues.

Expensive Remedy

Yet the body must pay a high price for any advantages resulting from the presence of fever. A temperature rise of roughly one degree produces a ten per cent increase in the protein metabolism of the body! Fever is an expensive therapeutic measure.

Sunstroke. In addition to fever due to infectious disease, there are two other pathological conditions in which the temperature is raised: namely, sunstroke and heatstroke. Sunstroke is caused by excessive exposure of the head to the sun's rays, and is due to heat congestion in the brain [Fig. 241]. It has an ancient history, the case of the son of the Shunammite woman (II Kings iv) being perhaps the oldest on record.

The brain becomes overheated, the cerebral arteries dilate, cerebral pressure rises, and nervous disturbances appear. Death can occur with extreme rapidity due to paralysis of the essential vital centres controlling respiration, cardiac activity, and vascular tension.

How Can Sunstroke be Prevented? The danger of sunstroke can be countered by avoiding any overheating of the head. The best protection is a light-coloured straw hat, because it is light and porous, and, owing to its light colour, reflects the sun's rays. It need not be worn constantly, but can be removed at intervals. Indeed, it is even expedient to do so occasionally so that the warm perspiring head can cool off by means of evaporation. There is but little danger of sunstroke when one moves about freely in the open—for example, in athletics—or, on the other hand, when the air passes rapidly over one's head—for example, at the seashore or riding in an automobile with the roof left open. Much more serious is the slow but increasing heating of the uncovered head, such as may occur at an outdoor meeting on a hot day or while watching a parade or some athletic event.

Heatstroke. Heatstroke is due to an excessive accumulation of heat within the body. It commonly occurs in individuals who are too heavily clad when the external temperature is very high, and who must exert themselves strenuously for many hours without a chance to rest and cool off. Soldiers and other people who must march heavily burdened for hours in close formation are particularly prone to heatstroke.

Dangerous Temperatures

Sudden attacks of heatstroke are also quite common among workers on tropical plantations, as well as among stokers in the boiler rooms of steamships, and miners in very deep mines such as the gold mines of South Africa. (These last two groups of workers are also exposed to another pathological condition produced by exposure to excessive heat, known as heat cramps.) Whenever the body becomes overheated and the heat cannot be adequately dissipated, it remains within the body and raises its temperature to pathologically high levels, such as 104°,

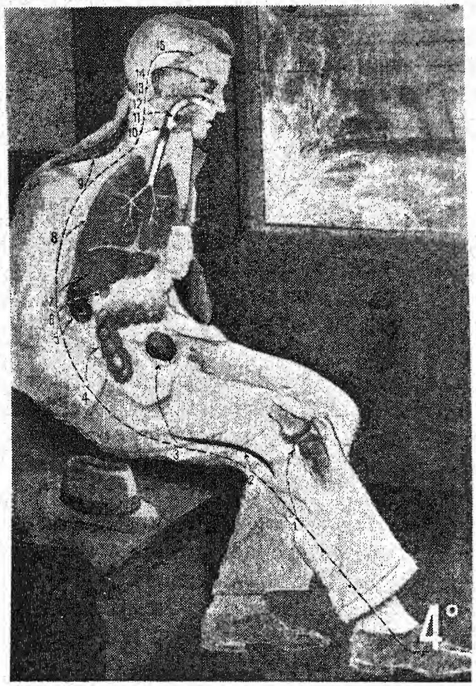


FIG. 242. *When the feet become cold, the blood vessels in various parts of the body contract, creating disturbances of the circulation. The form which any such disturbance may take depends on local conditions. Thus there may be found in the*

1. *knee-joint: joint pains;*
2. *sciatic nerve: sciatica;*
3. *urinary bladder: cystitis;*
4. *intestine: intestinal catarrh;*
5. *kidney: nephritis;*
6. *gall-bladder: cholecystitis;*
7. *liver: hepatitis;*
8. *lungs: bronchitis;*
9. *muscles: rheumatism;*
10. *larynx: laryngitis;*
11. *tonsils: tonsillitis;*
12. *nose: cold;*
13. *ear: otitis;*
14. *eye: conjunctivitis;*
15. *nerves of the head: neuralgia.*

110°, and even 116° Fahrenheit in the axilla, corresponding to a blood temperature of almost 122°.

The Dangers of Heatstroke. Heatstroke is a condition that may be fatal. The affected individual complains of headache, nausea, spots in front of his eyes; he then becomes pale, cold sweat pours down his face, he collapses and gasps for air. In more than half the cases if the temperature rises beyond 106° Fahrenheit, death results. Cases with temperatures of 110° are extremely serious and almost hopeless, yet isolated cases of recovery have been observed even after temperatures of 113°.

The Treatment of Heatstroke. An individual who has a heatstroke must be treated with the greatest care. Under no circumstances should he be permitted to walk even a short distance, but he must be made to lie down immediately. His clothes should be unbuttoned, and cold compresses placed on the head; stimulants should be given freely to combat cardiovascular collapse, and every effort made to reduce the temperature. Venesection may be useful for this purpose, also cold enemas, and icepacks. Rest is essential, and as far as possible any moving of the patient, even on a stretcher or in an automobile, should be avoided. It is not unusual for persons who have survived an attack of heatstroke to die suddenly several hours later because of the strain imposed on the cardiovascular system by the exertions resulting from transportation.

The Prevention of Heatstroke. On hot, sultry, humid days all strenuous athletic activities, long hikes, or

mountain ascents should be avoided. On such days the clothing should not be closely buttoned, nor should the knapsack which the hiker or climber carries be too heavy. Young untrained participants in such activities are particularly endangered; for this reason any predetermined programme should be changed and made less strenuous. Adequate rest intervals should be included, cool beverages should be drunk often, and moist cloths or handkerchiefs tied around the heads of the participants.

Warning Symptoms

Indications of heatstroke are: a feeling of heaviness in the legs, frequent yawning, headache, dizziness, noises in the ears, coloured lights and streaks before the eyes, and nausea. If one notices these signs in oneself or in other persons, immediate steps should be taken to prevent an attack of heatstroke before it is too late.

Colds. Fever, sunstroke, and heatstroke are pathological conditions in which the body is overheated: a cold is a condition in which the body is pathologically cooled. If a part of the body becomes cold, and this cooling is overcome by means of the heat-regulating mechanisms of the body, then the body has only been cooled. If this condition results in pathological consequences, the individual has caught a cold.

In Figure 158 has been shown the typical process by which an individual catches cold. Owing to the cooling of the feet, the conchæ of the nose contract and the virus which is present in the nose supplants the bacteria normally present there. This example is fundamental for all colds. The consequences arising from a cooling of the body do not generally make themselves evident in the cooled part itself, but rather in some distant part of the body. If the soles of the feet become cold, the vessels at any one or all of the points from (1) to (15) indicated in Figure 242 may contract. If the vascular spasm persists so that the nutrition of the particular organ is disturbed, a pathological condition is produced which we describe by saying that the individual has caught a cold in the particular part.

The blood vessels of the organs never contract simultaneously. In one person one group of blood vessels becomes spastically contracted, while in another a different group of vessels is thus affected; in one person this spasm lasts a few seconds while in a different individual it may take hours before the vessels relax; in some cases the bladder is most sensitive, while in others the nerves are most easily affected. Each person has a " disposition " for certain types of " colds."

Treatment and Prevention

Hot and Cold Applications. The blood supply of the organs can be influenced to a greater or lesser degree from various parts of the body, just as by way of the soles of the feet. If a hot application is placed on the abdomen, the vessels of the kidneys will dilate and perform their function as filters twice as rapidly; if an icebag is used, the vessels will contract and urinary filtration will be decreased [Fig. 244]. In a similar manner the blood-supply of the gall-bladder, the appendix, or an inflamed tooth is increased or decreased. If one wants to hasten an inflammatory process,

hot applications are employed: cold applications are used when it is desired to suppress such a process. It is by no means easy to decide what would be better in a given case, and it is part of the art of medicine to know when to apply heat or cold, and when to change from one to the other.

How Can I Protect Myself against Colds? Cold as such is not dangerous, but the cooling off of any part of the body is to be avoided. The actual degree of cold is less important than the temperature drop when the body is exposed. It is due to this that one catches a cold more easily while riding in a heated automobile or railway compartment where there is a cold draught than while travelling in an open car or a cold compartment. It is not so bad to work in a room which is only moderately warmed as to work in a room where one side of the body is kept warmer than the other. One should keep this in mind when selecting a place for one's desk or work-bench.

Women's Clothing

In addition to the cooling of the body a large number of other factors play a large rôle in the causation of colds: for example, climatic influences, bacteria, and viruses. The layman uses the word " cold " as if it were a simple matter, but for the scientist it brings to mind an entire series of problems that are still unsolved and will probably remain so for many years to come.

Modern women's clothing has demonstrated, surprisingly enough, that the body needs much less protection against cold than was formerly assumed. The modern woman has not succumbed to such prophesied maladies as severe colds, rheumatism, gout, kidney inflammations, or even tuberculosis as a result of her change to lighter clothing. She has not become chlorotic nor does she suffer any more than the women of earlier generations from gynaecological troubles. On the contrary, the result has been a generation of healthy, capable women.

Light Garments or Dark?

The Function of Clothing. The function of clothing is to provide the body with a private climate which will be more or less independent of the outer environment. In addition to this fundamental function, clothes must also fulfil a number of other requirements with respect to beauty, weight, porosity, protection against cold, etc.

A material appears light to us if it reflects rays of light that impinge upon it. It appears dark when it absorbs the rays. Underwear is generally white because it reflects the heat radiated by the body, thus returning it to the body. Our outer clothes are made of light or dark materials depending on the season. The light summer materials reflect the heat; the dark winter materials absorb it and conduct it to the body, so that the temperature of the climate in which we live underneath our clothes is raised. When the rays of the sun shine on it, a dark material acts like a hot application. Bathing-suits of dark materials are preferred because the wet body does not feel so cold under the dark colour. The light materials used for women's clothes reflect heat.

Clothes to Combat Moisture. In Figure 243 (a), (b), and (c) we see an actor in three situations which

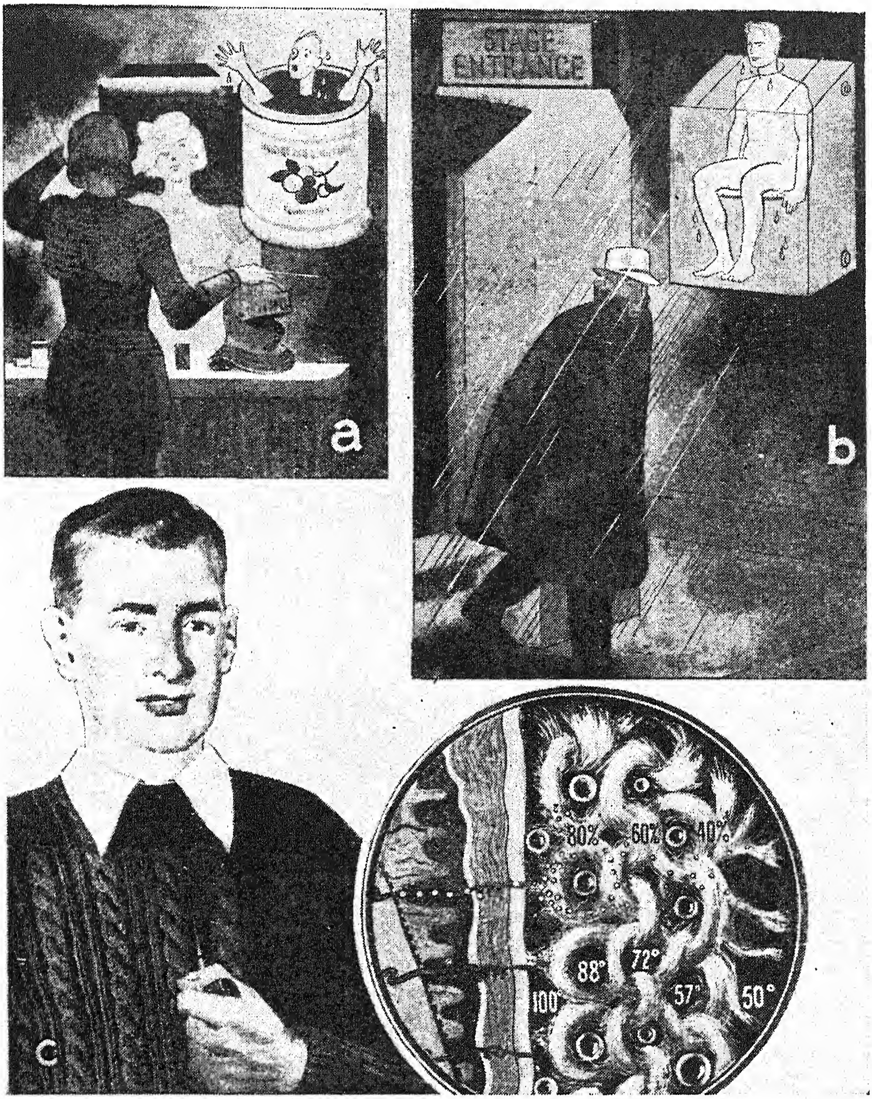


FIG. 243. *What is the ideal material for clothing? Metal? Rubber? Neither of these materials is porous, and so both are unsuitable for clothing. The actor in the suit of metal armour (a) perspires as if he were enclosed in a tin can. Not only does the rubber raincoat (b) keep the water out, but it also prevents the evaporation of moisture given off through the pores of the skin and creates an atmosphere around the body like that of a Turkish bath. But wool (c) is an ideal clothing material. Drops of perspiration are absorbed and retained by the wool fibres, so that they evaporate slowly, preventing a rapid loss of heat. Moreover, bubbles of air (shown, magnified, in circle), imprisoned among the fibres, isolate the body. The upper numbers, 80%—40%, indicate the humidity of the various layers of air, the remaining numbers their corresponding temperature.*

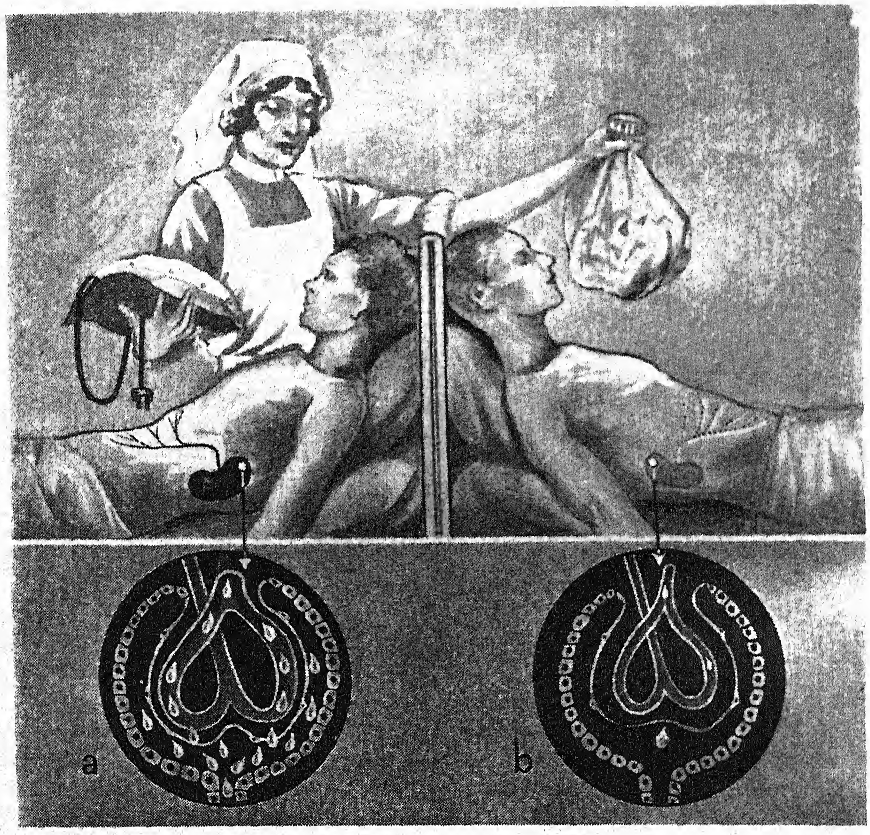


FIG. 244. *A warm compress (a) dilates the blood vessels, relaxes spasms, increases glandular activity and hastens inflammation. A cold compress (b) has the opposite effect —it contracts the vessels, slows down the circulation, and restricts the activity of the glands. Above is shown the effect of hot and cold applications on the kidney filters.*

arise in rapid succession. In (a) he emerges from a suit of armour in which he has played a classic rôle. He is naturally perspiring profusely, for the metal has shut off his body almost hermetically from the outer environment. As a result heat and moisture have collected within the suit of armour, almost as if he had been placed in a tin can. Ten minutes later we see him on his way home (b). It is raining and he is wearing a rubber raincoat. Rubber is likewise a poor material for clothing. It is used to keep the body protected against the flow of water. But while it prevents any outside water from coming into contact with the body, it also hinders any moisture arising underneath the coat from passing into the outer environment. As a result a person wearing a rubber coat for any length of time begins to feel as hot and wet as if he were sitting in a Turkish bath.

After another ten minutes the actor comes home (c). Thank goodness! He has left his suit of armour

behind him; now he hangs up his rubber raincoat, and sits in his room wearing a woollen pullover. Wool is an ideal material for clothing, because a wool fibre is able to absorb a great deal of water. If it is wet outside, it keeps this external moisture away from the body. It is because of this fact that woollen clothing is worn for winter sports, particularly those that take place on ice or snow. At the same time the wool fibre also absorbs the moisture produced by the body. This explains why wool is also worn for summer sports, and why athletes clothe themselves in heavy woollen garments immediately after participating in some strenuous event. They do this in order not to catch cold, and not because wool warms. After a game of tennis or football we do not want to warm up, but rather to cool off. We choose wool because in contrast to linen it absorbs perspiration and retains it, thus preventing, as a result of rapid evaporation, the production of an unpleasant and dangerous layer of cold air over the skin.

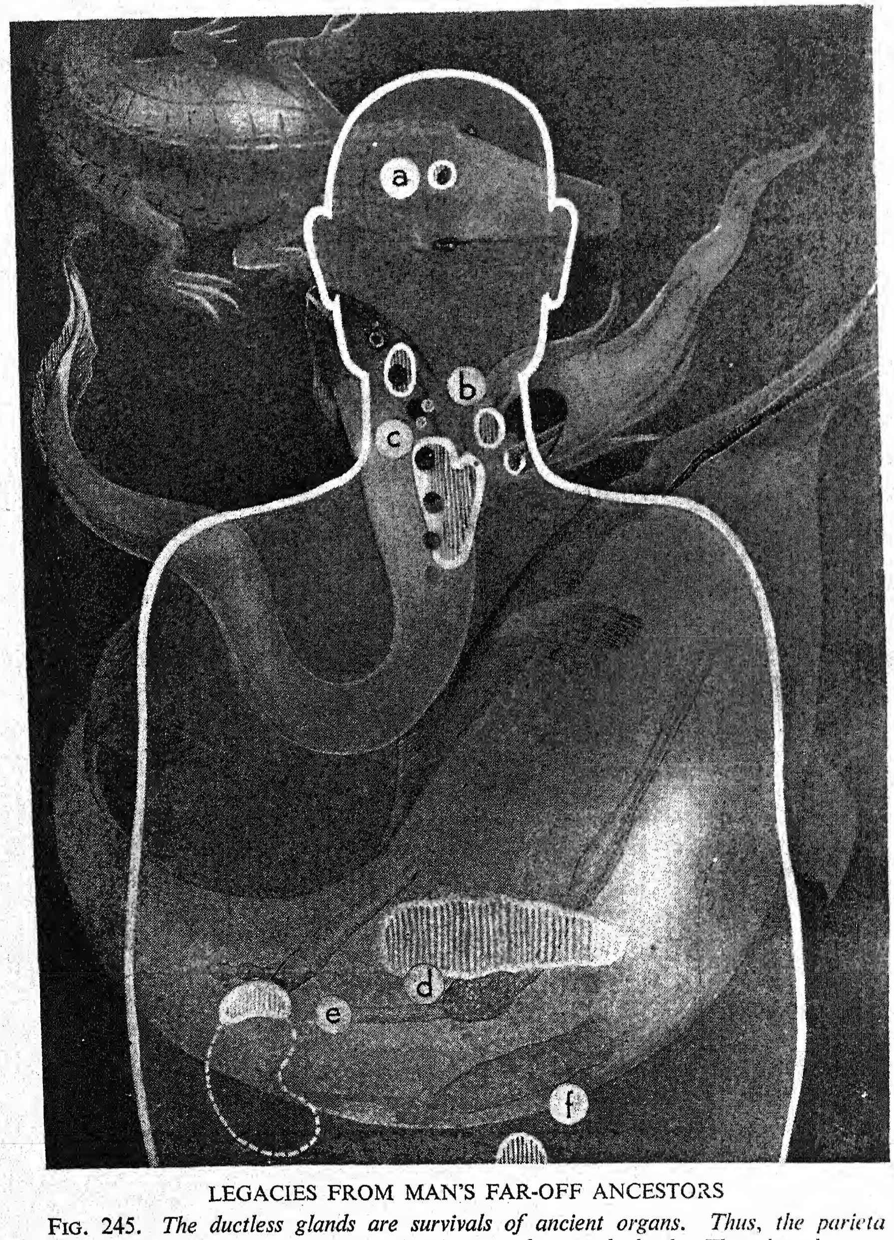
Air Bubbles

The Secret of Suitable Clothing—Air! The secret of a good material for clothing is its air content. Wool is such an ideal material not only because its fibres absorb and retain moisture, but because the wool fibres are peculiarly twisted and kinked, and very "stubborn." They do not lie close together, but remain separated by air bubbles, which they keep firmly between the rough fibres. A person dressed in wool walks about with a more or less permanent layer of air, a sort of private atmosphere.

Ideal Material

In Figure 243 (c) are represented the climatic relations in a woollen sweater. Moisture emerges from the sweat glands (left) and passes into the fibres, where it is retained. The air bubbles among the fibres exhibit a moisture content of 80 per cent near the skin; those somewhat farther removed have a content of 60 per cent, and the outer ones, from which the water evaporates, 40 per cent. Because of this slow drop in the moisture content of the air, the degree of cold produced by evaporation is slight. The temperature falls in the same slow manner, since air is a poor heat conductor. The air bubbles near the skin have a temperature of 88° Fahrenheit, while in the outer layers it is 57°, so that the skin hardly feels the true temperature of the outer environment. Thus a woollen material fulfils the requirements of a clothing material almost ideally.

By means of its absorptive power it regulates the passage of moisture from the skin to the outer world, and by means of the resting air bubbles it surrounds the body with a mild "oceanic" climate of its own.



LEGACIES FROM MAN'S FAR-OFF ANCESTORS

FIG. 245. *The ductless glands are survivals of ancient organs. Thus, the parieta eye (a) of the primitive amphibian has become the pineal gland. The ciliated groove (b) of early vertebrates has developed into the thyroid. The gill arches (c) of primordial fishes are the ancestral forms of the tonsils, parathyroids, and thymus. An ancient visceral gland (d) of fishes has become the present island tissue of the pancreas. The interrenal body (e) of early fishes is represented by the adrenal glands, while the mesonephros (f) has become a part of the sex organs in man.*

CHAPTER XXXI

Hormones

INTERNAL SECRETION. THE ENDOCRINE GLANDS. ENDOCRINE GLANDS AND NERVOUS SYSTEM. HORMONES. THE PINEAL GLAND. THE THYMUS. THE PARATHYROIDS. THE THYROID. IODINE. HYPERTHYROIDISM (GRAVES' DISEASE). MYXŒDEMA. CRETINISM. THE ADRENALS. THE PITUITARY GLAND. THE ANTERIOR LOBE—THE GROWTH GLAND OF THE BODY. THE POSTERIOR LOBE.

THE metabolic processes are regulated by substances secreted by certain glands into the bloodstream and carried by the blood throughout the body. These substances may be looked upon as chemical messengers, and for this reason they have been called hormones, from the Greek word *hormao*, "I urge." A typical gland functions according to the following principle [Fig. 246 (a)]. It receives its supplies from the artery (A) and manufactures the glandular secretions from the materials which it receives. The products of the gland then flow out through the excretory duct, either into the gastro-intestinal canal or on to the surface of the skin. The waste products are removed by way of the vein (V).

Internal Secretion

Glands producing hormones have no excretory ducts, and are therefore known as ductless glands or endocrine organs (b). Their cells also produce secretions, but they are not carried out of the gland by means of ducts. Instead they pass into the venous blood and flow into the interior of the body. For this reason the production of hormones has been designated internal secretion.

An endocrine gland produces only small quantities of hormone at any particular time. It needs no large glandular chambers and duct spaces, so that they disappear in many hormone glands. As a result such glands consist only of masses of cells separated by narrow spaces (c). The islands of the pancreas are glands that previously had ducts but now consist of cell masses [Fig. 193 (3)].

Ancient Survivals

The Endocrine Glands. Historically internal secretion must be very old, since the hormone glands of modern organisms have developed from extremely ancient structures of the animal body. It is possible that these structures were no longer needed in their original form and were therefore adapted to the production of hormones. The human body has eight large endocrine glands [Fig. 245].

1. The *pineal* gland developed from a primitive dorsal eye which was present in primordial vertebrates (a), but which lost its original function many millions of years ago.

2. The *pituitary* gland (hypophysis) developed from a duct which

led from the roof of the oral cavity to the brain.

3. The *thyroid* gland arose from an open groove in the floor of the pharynx of primitive aquatic vertebrates, such as the lancet fish, amphioxus (b). In this animal it is lined with mucous cells and supplied with cilia which keep the ingested food particles moving towards the digestive tube. In higher animals it has been transformed from a device for the mechanical manipulation of food into an endocrine gland producing a hormone.

4. The *parathyroids* and

5. The *thymus* developed from the gill pouches (c) [cf. Fig. 26]

6. The *island tissue* of the pancreas is a vestigial remnant of an old visceral gland of fishes, which has merged with the pancreas (d).

7. The *adrenal* glands are derived in part from the transformed interrenal bodies of fishes (e).

8. The *interstitial* cells of the sex glands are derived from remnants of the primitive kidneys that have wandered into the sex glands (f).

Like the vitamins, hormones are

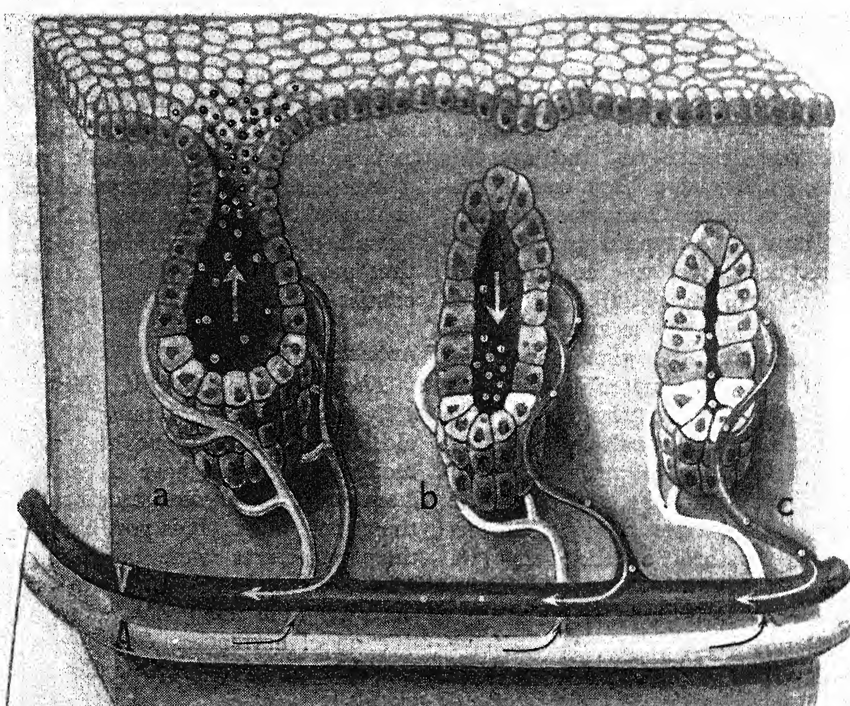


FIG. 246. *Internal secretion. A typical gland (a) receives raw materials from the blood by way of the arterial system (A). From these materials it manufactures specialized substances and secretes them through a duct to the skin or mucous membrane. If the secretory duct is absent (b), the gland becomes a gland of internal secretion—that is to say, it secretes its products directly into the blood-stream in a vein (V). Since internal secretions, or hormones, are produced only in small amounts, the space within the gland disappears (c) and the gland becomes a solid cellular structure.*

needed only in extremely small quantities. Consequently the endocrine glands can also be small. In many parts of the body cellular masses have been observed whose significance is as yet unknown. It is possible that these bodies are also endocrine glands whose function has not yet been elucidated. There are probably more hormones produced in the body than we know about at present. We know today that the liver produces several hormonal substances, and the same is also true of the gastric wall.

Endocrine Glands and Nervous System. Another remarkable circumstance is the fact that in the course of the history of the body various glands have wandered about and attached themselves to other organs. In this manner interesting symbiotic arrangements, or communities of existence, have developed between endocrine glands and other organs. The island gland merged with the pancreas; the gland of the former dorsal eye wandered down into the brain and became the pineal gland; the gland in the roof of the oral cavity has travelled upwards into the brain and attached itself to the latter as the pituitary. It has now become a mixed organ, one part consisting of this gland, and another part being derived from the nervous tissue of the brain.

Gland Partners

The adrenal glands are also attached to the nervous system, and at present are also mixed organs, derived in part from the abdominal sympathetic nerve apparatus. The gland cells of the thymus have united with lymphoid tissue, etc.

The Interaction of the Endocrine Glands. These glands of internal secretion are coupled with each other so as to form functional groups. One of these functional systems consists of the triple alliance: pineal-thymus-sex gland. The first two are youth glands, and serve to develop the youthful body. The third one, on the other hand, the sex gland, is the gland of maturity.

Plant Hormones

During years of childhood the pineal and the thymus are believed to be active. After the tenth year these two glands begin to involute; at the same time the sex gland becomes active and produces sexual maturity or puberty. Similar functional relations also exist between other endocrine glands. The thyroid, pituitary, and adrenal glands are all connected with the sex gland. The pituitary is the "starter" for the motor of the sex gland. It dispatches hormones that bring about maturation of the sex gland.

Hormones. Hormones and prehormones are widespread in nature. Plant blossoms contain the same "maternity hormone" as the female ovary. Similarly, digitalis, the well-known heart poison and heart remedy which is obtained from the foxglove, is closely related chemically to the hormones of the ovary. The iodine-containing hormone of the thyroid is likewise present in algæ in a preliminary form. This close relationship explains the interesting fact that ovarian hormone influences sexual development not only in human beings and animals but also in plants [Fig. 250].

Hormones, like vitamins, act in unimaginably minute quantities. By means of its hormone the adrenal gland affects all the organs in the body. Yet in an entire year the

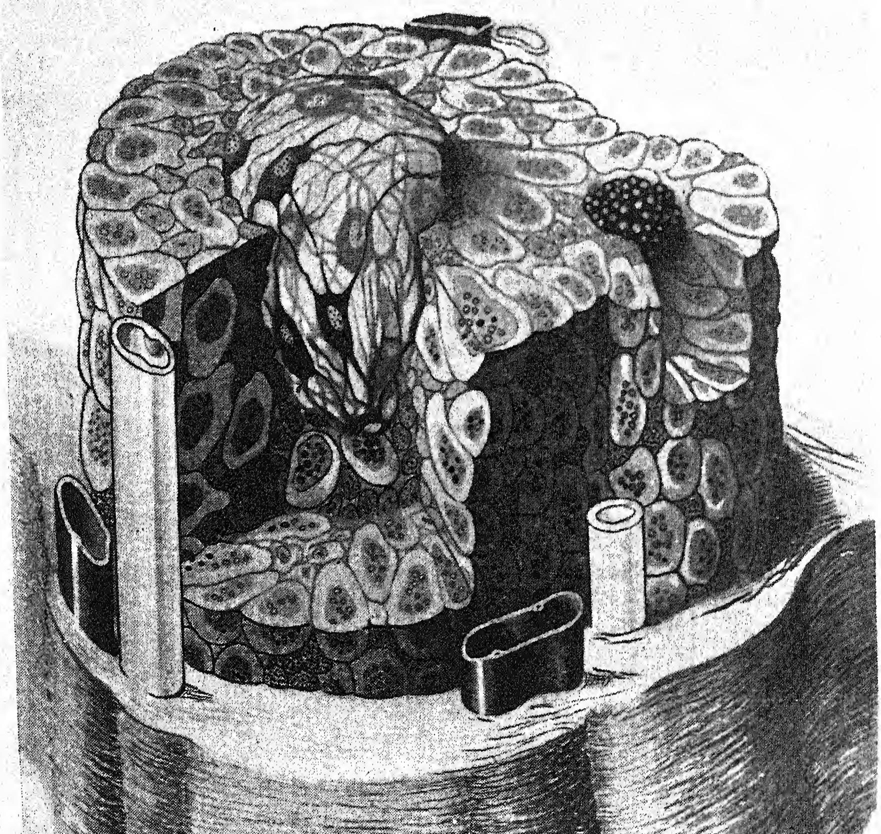


FIG. 247. *A drawing of the internal structure of the pineal gland, showing (greatly enlarged) some of the different types of cells of which it is composed. The functions of the pineal gland are obscure. It is possible, however, that the effect of its hormone is to restrain the activity of the sex gland; possibly, too, it is associated with growth.*

adrenal glands do not produce more than one gramme of hormone. Three spoonfuls are sufficient for an entire lifetime! If a castrated rooster that does not present even the slightest sexual characteristics is injected three times in the course of a week with $\frac{1}{30000}$ gramme of sex hormone, the animal's comb begins to grow and he commences to crow. Owing to the secretion of such minute quantities into the blood, a boy becomes a man, and a girl a woman, both physically and mentally. The youthful personality unfolds and develops, turning the child into an adult.

The Pineal Gland. We do not know anything positive regarding the function of the pineal gland. There is some evidence to suggest that it produces a hormone associated with sexual and skeletal development. The pineal gland apparently restrains the action of the sex gland. Pathological conditions

of the pineal body in boys, such as tumours, are accompanied by the development of virilism and hirsutism, as well as undue tallness. It is by no means certain, however, that there is a direct causal relationship between the two conditions in such cases.

The Thymus. A second youth gland is the thymus, situated in front of the trachea. The size of the thymus is its most striking and significant feature. The average weight at birth is 13 grammes; it increases gradually until the gland weighs about 35 grammes at puberty. Thereafter there is a gradual involution and atrophy of the gland. This interesting course of development would seem to suggest some relationship to genital development.

In its structure the thymus gland consists partly of lymph cells and partly of epithelial cells. At first the gland is entirely epithelial in character, being derived from one of the gill clefts of the embryo. Later, however, in the course of embryonic life, it is invaded by lymph cells. The epithelium remains in the form of small spherical corpuscles, in which the cells are arranged in layers like those of an onion [Fig. 249].

The Parathyroids. Between the tonsils and the thymus a pair of tiny glands develops from the middle gill cleft. Although they do not weigh even one gramme, they secrete an extremely important hormone.

Calcium Regulation

These bodies are called parathyroid glands because they are situated alongside the thyroid. The parathyroids regulate the blood calcium level, determining the transport of calcium from the bones into the blood stream and the tissues, and thence into the urine. The calcium ingested with the food is first deposited in the bones and then delivered to the blood as required. If parathyroid hormone is lacking, the body becomes deficient in calcium. Calcium inhibits the neuromuscular irritability of the tissues. In organisms deficient in calcium the muscles begin to twitch, and spasms and convulsions appear. This condition is known as tetany. Parathyroid extract (parathormone) is the best remedy for the treatment of tetany due to parathyroid deficiency.

The Iodine Organ

The Thyroid. Touch the front of your neck gently, without squeezing too hard, and you will feel the two soft pads, each about the size of a walnut, in front of the harder cartilages. This is the thyroid gland, so called because it is situated just in front of the thyroid cartilage. The thyroid is the iodine organ of the body.

Iodine in Nature. Iodine is extensively distributed in nature [Fig. 251]. There must be millions of tons of iodine in the earth. Iodine is derived chiefly from the weathered rocks of mountains (1) and is swept into the valleys by mountain streams (2). Therefore many mountainous regions are strikingly deficient in iodine. Among civilized countries, for example, Switzerland is one of the poorest in iodine—perhaps because the rapidly flowing mountain streams remove the iodine too rapidly. Owing to the circumstance that most rivers eventually empty into the ocean, iodine, like salt, has collected there (3). Ocean water has a high iodine content. Some of the iodine passes into the atmosphere (4). The plants and animals of the

ocean are rich in iodine. The highest iodine content is present in the ordinary bath sponge (6), and the fish that are richest in iodine are haddock and cod. The common plaice and the herring have a relatively low iodine content. Cod-liver oil, which despite its unpleasant taste must be considered a veritable treasure chest of the most valuable substances, also contains a great deal of iodine.

The Iodine Cycle

Iodine is precipitated from the atmosphere by rain, dew, and fog, so that after rain the air is free from iodine and the soil has been enriched (5). The quantities of iodine that pass into the soil with the rain are by no means small. It has been estimated that in Switzerland in the course of one year more than 40,000 pounds of iodine are precipitated together with rain. The looser the surface soil, the more rapidly does the earth absorb the iodine and the more firmly is it retained. For this reason ploughed land is richer in iodine than uncultivated country, and disintegrated, crumbled rocks contain more iodine than tightly packed clay soil. Acids likewise attract iodine. It is because of this that the humus of rotting leaves, which is very acid, also has a high iodine content. Coal which has arisen from humus contains a great deal of iodine (7), so that the smoky air over industrial regions is relatively rich in iodine (8).

Iodine in Foods. From the soil iodine passes into plants and thus into foods. Among the plants used for cooking, garlic has the highest iodine content (9). In southern countries, where it has a less penetrating taste than in the north, it has been highly praised and esteemed since ancient times as a food and therapeutic remedy. Garlic contains four times as much iodine as the onion, which also has a high iodine content, and five times as much as the radish and the lemon, both of which also contain iodine. Among our daily foods eggs, milk, and butter contain iodine (10 and 11).

Iodine in the Human Body. The human body contains approximately $\frac{1}{20}$ gramme of iodine. A part is stored in certain organs, while the rest circulates with the blood, which constantly delivers iodine to the cells. In all healthy people in all parts of the world the iodine content of the blood is fairly constant and subject only to slight variations. In summer the iodine content of the blood is somewhat higher than in winter, and in women it rises during the monthly period, which may perhaps explain the increased irritability of women at such times. If a person becomes excited, his glands pour out iodine, and the iodine content of the blood is doubled. This increase may be demonstrable for as long as two hours. The well-known fact that people can talk themselves into a state of anger, and become more and more excited in the course of an argument, may perhaps be explained by this outpouring of iodine during excitement, since iodine itself in turn produces an exciting effect.

How Iodine Affects Man

Among the organs of the body iodine is unequally distributed. Half the iodine of the body is present in the musculature, one tenth in the skin. The endocrine glands are richest in iodine. It apparently plays a part in hormone-formation.

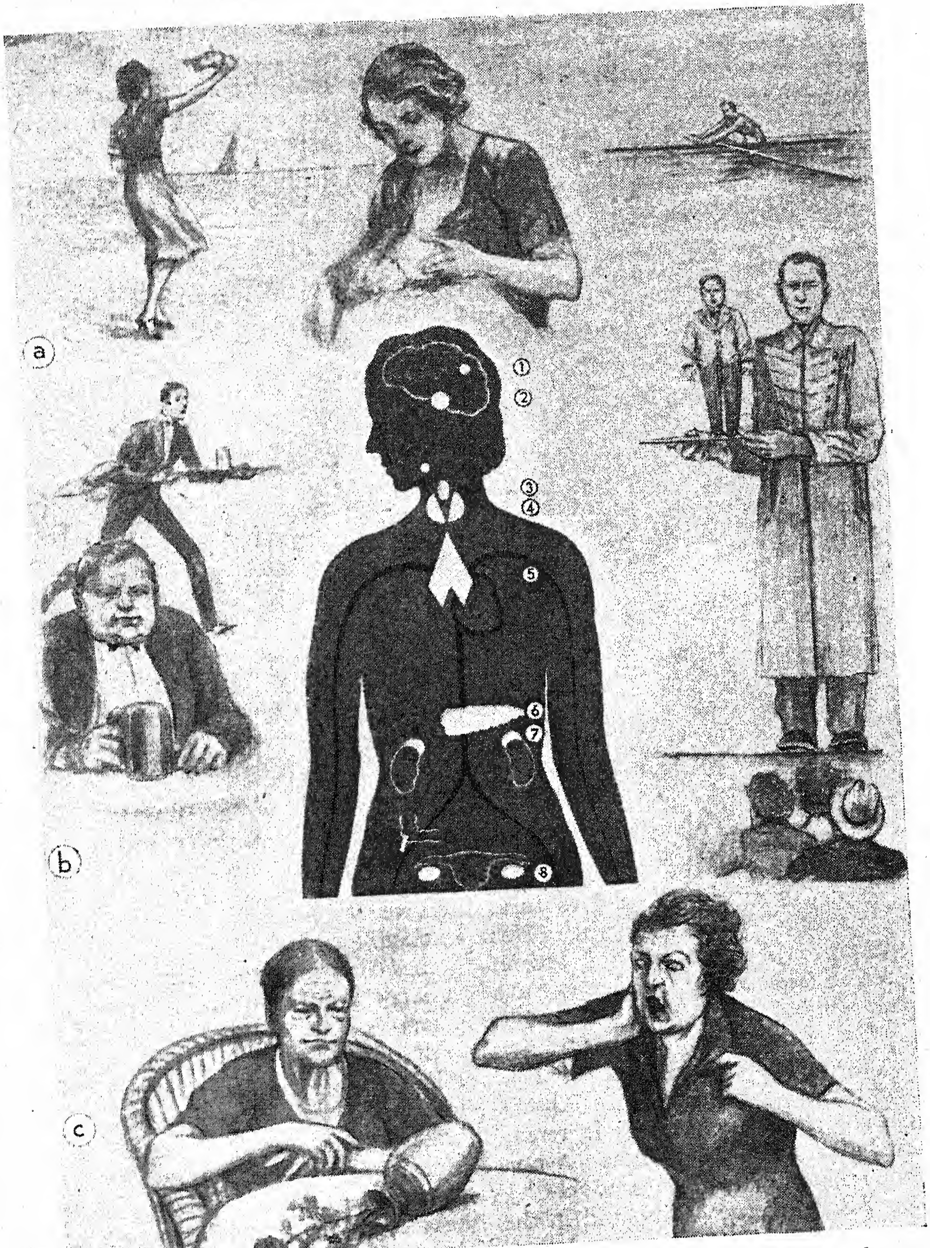


FIG. 248. *The influence of the endocrine glands is profound, affecting every phase of human life. The diagram (Centre) shows the position of these glands; they are: (1) the pineal, (2) pituitary, (3) parathyroids, (4) thyroid, (5) thymus, (6) pancreas, (7) adrenals, (8) sex glands. Between them, the endocrine glands determine (a) sex, (b) growth and physical constitution, (c) temperament.*

The ovary is rich in iodine—as long as it functions. With the appearance of the menopause its iodine content decreases.

The chief iodine depot is the thyroid gland, which weighs approximately one thousandth of the weight of the body, but which contains one fifth of all the iodine in the body. In the thyroid the iodine is com-

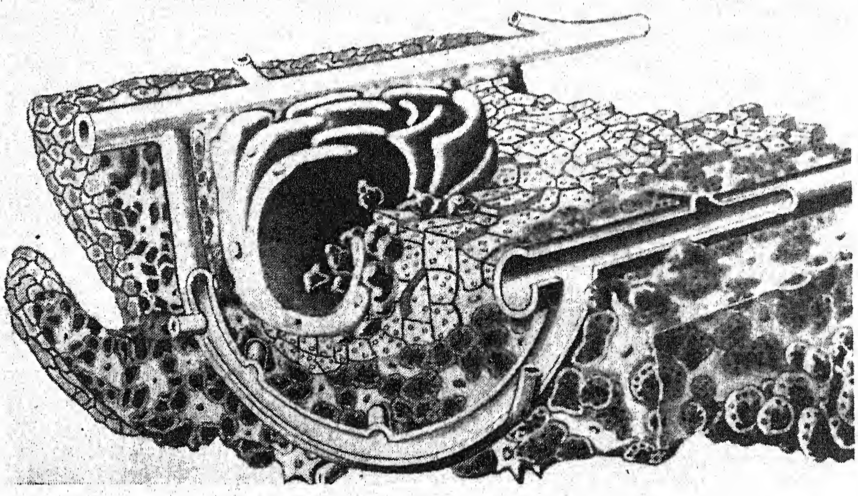


FIG. 249. *One of the corpuscles (much enlarged) which compose the thymus; they number about one and a half million. The function of this gland is unknown.*

bined with an amino acid to form a compound called thyroxin. This substance is united with a second protein compound, and these two are combined with a third protein molecule containing arsenic. This highly complex triple compound is known as the colloid of the thyroid gland, because externally it resembles a colloid like gelatine. A normal thyroid gland produces $\frac{1}{10}$ gramme of colloid daily, and in the course of a lifetime it works up about $\frac{1}{5}$ gramme of iodine.

Iodine stimulates the sympathetic nervous system, which controls the metabolic processes. Administration of iodine raises the rate of metabolism, stimulates the activity of the glands and the intestine, and increases the motility of the wander cells and irritability of the nervous system. The thyroid is the temperament gland of man. In order to determine what sort of temperament an individual has, one might ask: How much iodine does his thyroid secrete? The thin maid who runs excitedly through the room, who becomes frantic over trivialities and upsets the entire household, has too much iodine in her blood. The waiter in Figure 248, who is unduly tall owing to an overproduction of hormones, and who passes rapidly among the guests, his coat tails flying, is a similar type. The fat, phlegmatic man who sits placidly behind his beer mug probably has a thyroid which does not function very actively.

Hyperthyroidism (Graves' Disease). If the thyroid enlarges and secretes too much hormone, a con

dition arises which is known as hyperthyroidism, or Graves' disease, after the physician who described the disease in 1835. Enlargement of the thyroid is known as goitre. Since a moderately enlarged thyroid which exhibits increased vascularity and often even pulsation, accompanied by protrusion of the eyes (exophthalmia) may be observed in people with Graves' disease, the condition is also known as exophthalmic goitre.

Graves' Disease

The symptoms typical of Graves' disease are due to excitation of the sympathetic nervous system. The four chief signs are enlargement of the thyroid gland, exophthalmia (which may be absent), palpitation of the heart, and a fine, involuntary tremor which is best seen when the arms are extended and the fingers spread wide apart. The blood-pressure is raised, the pulse rate accelerated, and the metabolism of the body increased. The individual perspires easily, he is excitable and irritable, diarrhœa and vomiting may occur, and there is a marked loss of weight.

Myxœdema. If the thyroid produces too little hormone, a state of hypothyroidism develops. When the basis of the condition is congenital it is known as cretinism, and when acquired, as myxœdema. Metabolism is depressed, the individual is mentally and physically torpid, the skin is rough, dry, and sensitive to cold, the hair is dry and falls out, the blood-pressure is lowered, the heart beats slowly, the sex glands function poorly, and the patient lacks temperament. In Figure 248 the woman who looks on listlessly while the vase with the flowers is upset, and the hyperthyroid woman becomes frantic, is suffering from myxœdema.

Cretinism. If a child is born without a thyroid or with a degenerated gland, it remains mentally and physically undeveloped. Often it does not even learn to speak and exhibits no reactions to its environment. Such an individual is called a cretin. Many cases of congenital cretinism are hopeless and do not respond to any treatment. Some cretins, however, develop remarkably when they receive thyroid medication, learn to speak and to perform some easy type of work, and can be maintained in a state of social usefulness by the constant administration of thyroid extract.

Endemic Cretinism. Cretinism may be endemic or sporadic. The endemic form is common to the upland valleys of the Alps and the Himalayas, regions where endemic goitre is also prevalent. The thyroid gland is enlarged, thick, hard, and atrophic. The glandular tissue may disappear completely, only a hard fibrous mass remaining. It differs fundamentally from the comparatively smaller, soft gland of a patient with Graves' disease.

Arrested Development

In the latter case, enlargement of the thyroid is due to excessive function; the goitre of the cretin is a thyroid that has become enlarged because it attempts to compensate for its iodine deficiency, and which remains large when it atrophies, owing to exhaustion. Cretinism develops insidiously. The child at birth has no goitre and often learns to speak and to act. It recognizes its environment and appears normal. Within a few years, however,

unless the child is removed to a non-goitrous district or receives iodine medication, cretinism begins to develop. The mental and physical development of the child slows down and eventually ceases; the final result is a cretin like the little woman in Figure 251 (12) and the man in Figure 252. Cretinism is widespread in the Alpine districts. In Savoy there are 40,000 goitrous individuals among 1,000,000 inhabitants. The Aosta Valley presents the greatest number; here approximately one third of the population is affected. Cretinism is rare in districts rich in iodine.

If the disease has progressed too far, iodine no longer helps. The outbreak of the disease, however, can be prevented or at least greatly limited by the administration of iodine. For this reason the population in such districts is supplied with iodine. It has already been mentioned that cretinism and goitre occur together. Now, simple goitre is due to an insufficient supply of iodine to the thyroid. If a goitrous woman becomes pregnant she is unable to supply her child with the needed iodine, and as a result a cretinous child is born. If iodine is supplied to the entire population, the pregnant mother is almost certain to receive a sufficient amount to prevent her child from becoming a cretin.

In addition to supplying the population with iodine the soil is

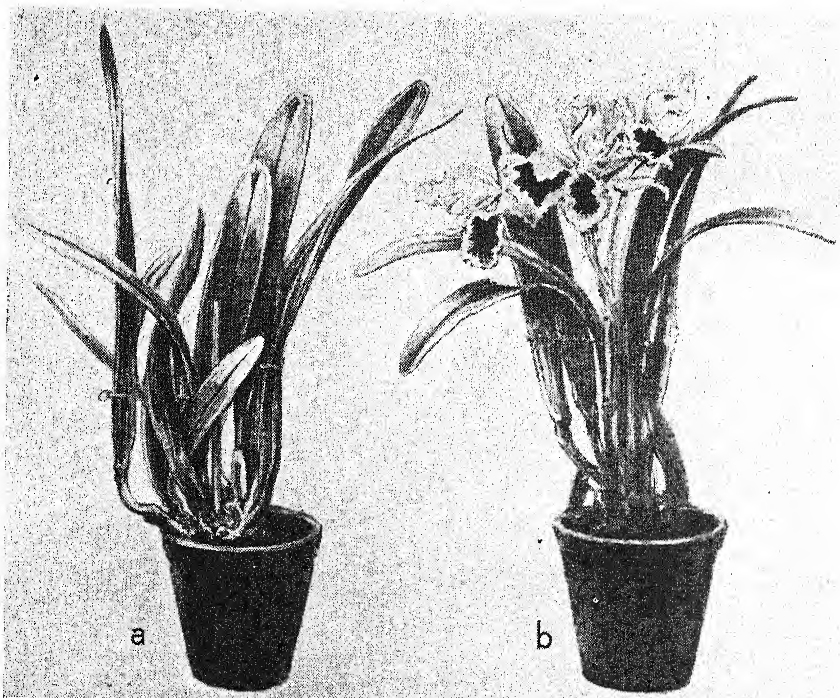


FIG. 250. *Plants also react to hormones! After treatment with ovarian hormone, plant (b) becomes sexually mature and blooms sooner than plant (a), which is of the same age.*

fertilized with compounds containing iodine, and the feed of domestic animals such as cows and chickens is mixed with iodine, so that the milk, butter, eggs, and meat obtained have a higher iodine content.

Preventive Treatment

In the United States iodine is administered to the population of goitrous regions—for example, the region of the Great Lakes and the valley of the St. Lawrence—in the form of iodized salt. This is also done in Switzerland. Half a gramme of potassium iodide is added to every hundred grammes of table salt, so that the individual obtains a considerable part of his iodine requirement by means of table salt.

The Adrenals. The adrenals are the best known of all the endocrine glands. The adrenal gland has a very ancient evolutionary history, having developed from a primitive organ, the interrenal body, of fishes. Elements of the sympathetic nervous system wandered into the interior of the interrenal body, and are situated within it at present like a nut in its shell. The kernel of the nut, consisting of nerve cells, is the medulla, and the shell, which is derived from the ancient interrenal gland, is known as the cortex of the adrenal. Both produce hormones. The medulla secretes adrenalin, which stimulates the sympathetic nervous system, while the cortex acts on the vagus. Thus the same organ produces two oppositely acting substances!

The Hormone of the Adrenal Cortex. The investigation of the adrenal cortex has led to the isolation of various crystalline compounds. This has raised an important question as to whether the adrenal cortex elaborates a single compound which can be regarded as the hormone of the gland, or whether it manufactures a number of separate hormones, each with a special function. Research on this problem indicates that no one compound can be regarded as the essential hormone which produces all the physiologic effects of the cortex. Some of the functions of the body which are influenced by the adrenal cortex are carbohydrate metabolism, kidney function, the capacity of muscles to respond to stimulation, growth in young animals, and resistance to stress produced by such agents as bacterial toxins, insulin, and thyroid hormone.

Adrenalin. Adrenalin is one of the most powerful substances in the body known to us. It is present in the blood in dilutions ranging from 1 : 2,000,000,000 to 1 : 1,000,000,000. Let us think of the molecules of the blood as peas and the adrenalin molecules as beans. Now if an adrenalin bean were placed on a page of this book and peas placed side by side to the next bean, they would have to be laid from here to the moon, once around the moon, and then back to the earth before the next adrenalin bean was reached.

A Versatile Hormone

Such is the great dilution in which it is present in the body and exerts its action. It is one of the strongest "poisons" known to us. Some of the most important effects of adrenalin are indicated below:

1. It acts like an oxidative ferment during nerve-cell activity.
2. It dilates the pupils.
3. It contracts the capillaries.
4. By contracting the capillaries

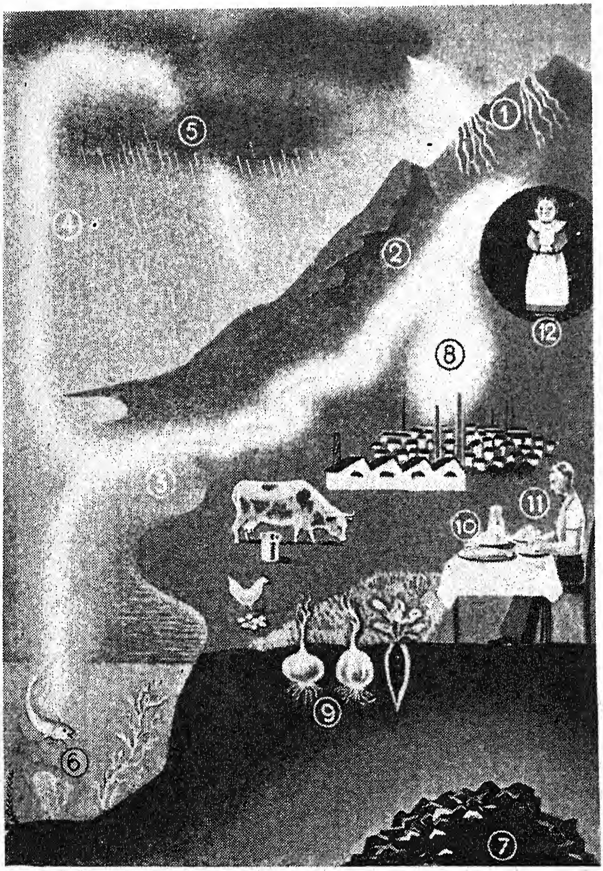


FIG. 251. *The circulation of iodine in Nature. This very abundant and widely distributed mineral is washed out of broken-down rocks (1) by mountain streams (2), and eventually accumulates in the ocean (3), where organic life is particularly rich in iodine (6). The atmosphere (4) takes some of the iodine from the sea, later to be returned to the earth in rain (5), which enriches the soil and its products (9, 10, 11) with iodine. Coal (7)—a vegetable product—and hence, too, the smoky air pervading cities (8), also contain iodine originating in this way. The mountain valleys from which the iodine was originally washed away, have become relatively deficient, so that natives of these localities commonly exhibit cretinism (12).*

it renders the mucous membranes anæmic, thus reducing congestion—for instance, in the nose.

5. Adrenalin seems to play a part in the formation of skin pigment. When a person is affected by disease of the adrenals the skin becomes pigmented, ranging in colour from light yellow to deep brown. It is possible that adrenalin plays a role in this process.

6. Adrenalin raises the blood-pressure.

7 It has an opposite effect on the bronchial tubes and the intestine. The bronchial tubes dilate and the intestine relaxes under its influence.

8. The tonus of the heart muscle is increased.

9. Adrenalin mobilizes the sugar from the liver.

This multiplicity of effects explains the equally varied uses to which adrenalin is put in medicine. Some of these uses are as follows:

1. In inflammation of the eyes it is used to dilate the pupils.

2. Since it reduces the congestion of mucous membranes, it is used in examination of the nose to reduce the size of swollen nasal conchæ. Adrenalin is sometimes used in colds where the nose is clogged, but since its action is of short duration it has

been replaced by other substances such as ephedrin.

3. Since it relaxes bronchial spasm, it is a valuable remedy in the treatment of asthma.

4. Allergic individuals who have attacks of hives after eating strawberries, tomatoes, crabs, and oysters are relieved by injections of adrenalin.

5. In performing operations where local anæsthesia is used, as in dental extraction and tonsillectomy, the doctor adds a few drops of adrenalin to the cocaine which is used for anæsthesia. In the first place the adrenalin renders the tissues anæmic, thus lessening the danger of bleeding, and secondly it retards the absorption of the anæsthetic, thus prolonging its effect.

6. In cases where the heart suddenly stops, as in serious accidents, or under the influence of an anæsthetic, adrenalin is injected directly into the heart as a last resort, since there is no stronger stimulant for the heart muscle. Many a "corpse" has been recalled to life by a timely injection of adrenalin—to be sure, only in the first two to four minutes after the heart has stopped beating. A person who has been dead for an hour cannot be revived, because the blood is already coagulating in the blood vessels and the circulation is thus irrevocably occluded.

The Pituitary Gland. The pituitary is not only a double organ, but even a triple one. It consists of two lobes, an anterior and a posterior, the latter consisting in turn of two parts, and exerts a variety of effects [Fig. 253].

The Anterior Lobe—the Growth Gland of the Body. The anterior lobe is derived from an ancient structure of the oral cavity, a pouch which arises as an upgrowth of the pharynx and which in the course of the evolution of the human body has become attached to the under surface of the brain. The anterior lobe is a growth gland. The size of the body and, above all, its proportions are primarily dependent on the influence of the anterior pituitary. If a young animal is deprived of its pituitary, it remains dwarfed. Removal of the anterior lobe in a tadpole prevents its metamorphosis into a frog. If an extract of the lobe is injected, however,

FIG. 252. *A typical cretin, or sufferer from thyroid degeneration. This condition is due to iodine deficiency in the soil.*

metamorphosis takes place. Many dwarf types—among dogs, for example, the dachshund—owe their dwarfed form to a considerable diminution of the anterior lobe. Conversely, if the pituitary functions too vigorously, the bones grow beyond the normal size. Most giants,

such as those in Figures 56 and 248, are pituitary giants.

Acromegaly. If the anterior lobe grows larger in adult life after skeletal ossification has ceased, the skeleton begins to grow again. But since the growth zones of the skeleton have already become firmly knit, only the free ends of the bones of the nose, chin, feet, and hands are able to grow. For this reason this disease is known as acromegaly, from the Greek *akros,* "extremely," and *megale,* "large." Most giants show signs of acromegaly: namely, great enlargement of the hands and feet, while the head and trunk are relatively small.

Besides the growth hormone the anterior lobe also secretes other hormones that act on the other endocrine glands—above all, the thyroid and the sex gland. Without the hormone from the anterior pituitary the sex gland cannot begin to function, so that the anterior pituitary has been described as the "starter" of the sex gland.

The Posterior Lobe. The posterior lobe of the pituitary is intimately connected with the metabolic centres in the depths of the brain. By means of a hormone it regulates the oxidative processes in the muscles, water metabolism, and heat-production. When the posterior lobe is diseased, the individual excretes enormous quantities of water, up to as much as twenty quarts of urine in one day, and suffers severe thirst; or he may waste away because of pathologically intensified oxidations and die within a few months.

The posterior lobe, like the adrenal, is composed of gland tissue and nerve cells. It produces a number of hormones, of which one contracts smooth muscle fibres, as does adrenalin, thus raising the blood-pressure; another stimulates the intestinal movements; a third acts on the kidney, increasing its power to absorb water and thus diminishing diuresis; while a fourth causes the uterine muscle to contract, the effect being particularly marked towards the end of pregnancy. This last substance, known as pituitrin, is used in obstetrics occasionally to initiate labour, but mainly to obtain rapid womb contraction after childbirth.

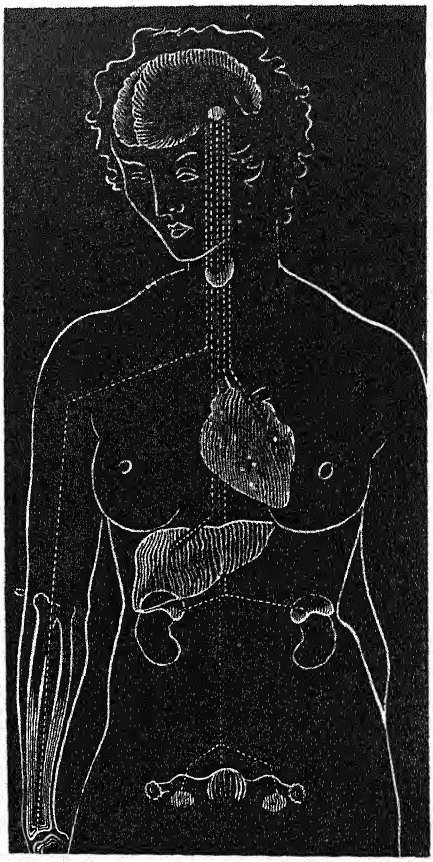


FIG. 253. *The pituitary gland acts upon the brain, the bones, thyroid gland, heart, liver, adrenals, sex glands and uterus.*

CHAPTER XXXII

The Urinary Organs

THE KIDNEY. INTERNAL STRUCTURE. PREPARATION OF URINE. COLLECTING TUBULES, KIDNEY PELVIS AND URETER. KIDNEY DISEASES. THE TESTING OF RENAL FUNCTION. URINARY CASTS. KIDNEY STONES. URINARY BLADDER. THE COLOUR OF THE URINE. UREA. URIC ACID.

THE old anatomists called the kidney *viscus elegantissimum*, the most elegant of the viscera, and it is actually that. From its external appearance to the last microscopic details, the kidney surpasses the other organs in the profusion of æsthetic motifs to be found in it, and in the elegance with which its structural problems are solved.

The kidneys are two chocolate-coloured, bean-shaped bodies, each as large as a fist, suspended in the lumbar region on the posterior wall of the abdomen [Fig. 259]. They are not enclosed in the peritoneum like the stomach, intestine, and liver, but hang with relative looseness near the spinal column, and consequently have a tendency to sink down. If the ligaments that hold the kidneys in place become relaxed, they begin to move about (floating kidney).

The Internal Structure of the Kidney. During the development of the kidney within the embryo, a tube, which later becomes the ureter [Fig. 254 (I)] and carries away the urine from the kidney, grows towards the developing organ and sends out antenna-like sprouts (a) into its interior. These meet blood vessels (shown as black lines), which grow from the kidney. Both the urinary canals and the vessels ramify, and their branches (b) meet each other at their tips. The blood vessel, however, on meeting a ureter, pushes in its tip, making a cup-like depression in which the vessel coils [Fig. 254 (c); Fig. 256 (c); Fig. 257]. This apparatus is the kidney filter, the place in which the urine is prepared and filtered. In all illustrations the urinary filter is represented

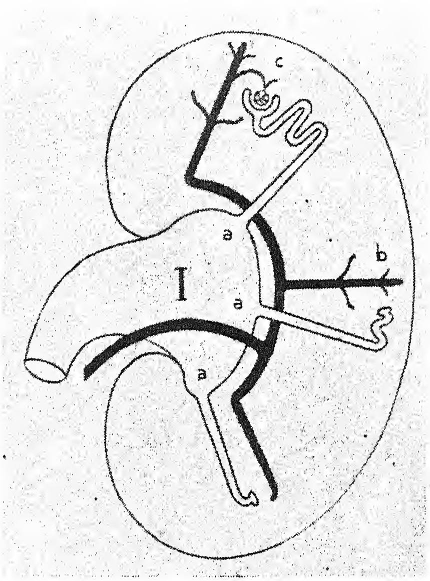


FIG. 254. *The development of the kidney in the embryo. The urinary ducts (a) grow out of the kidney pelvis (I) into the kidney. Here they unite with blood vessels (in black) to form the filters (c).*

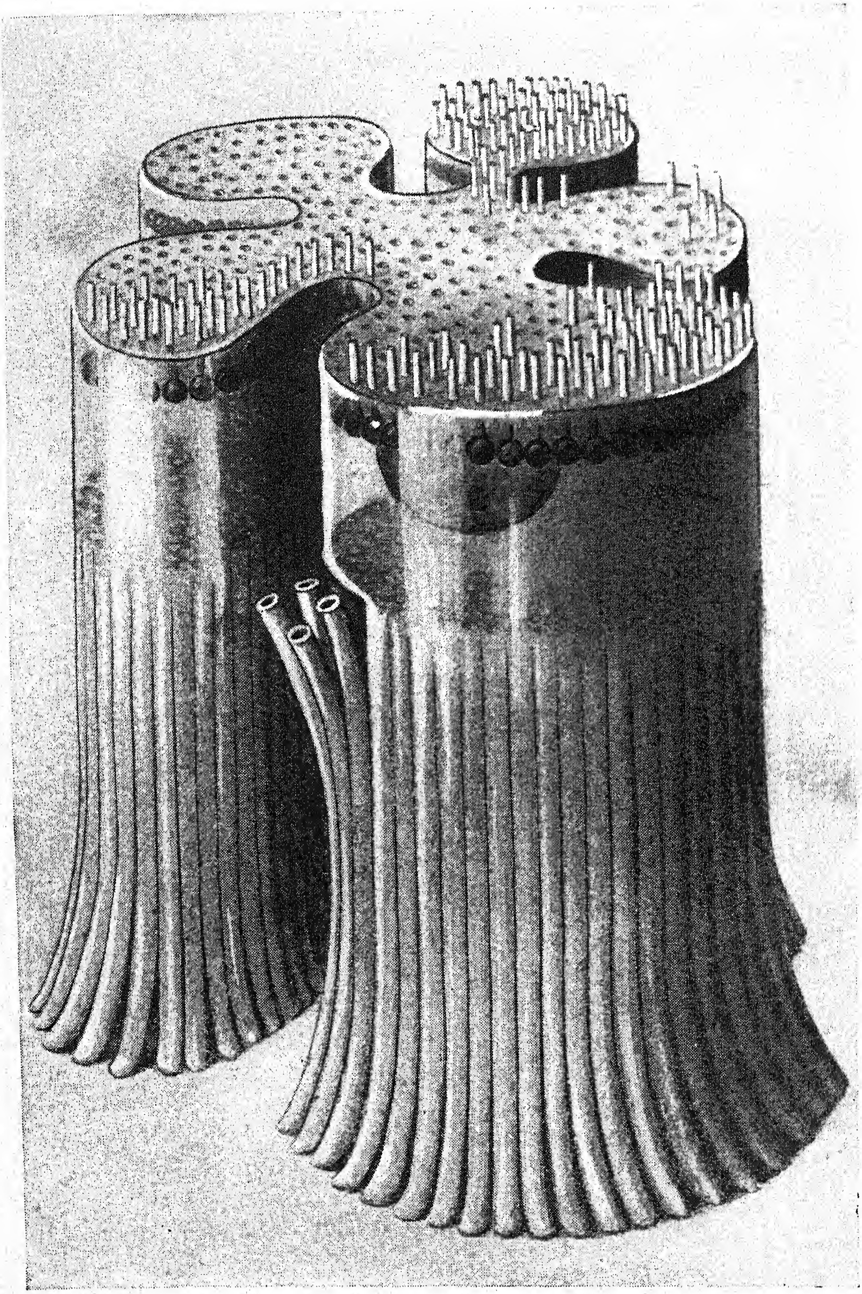


FIG. 255. *One of the fifteen thousand cells which line the walls of each of the minute filters of the urinary canal. Together these cells comprise the apparatus which filters water and waste products from the blood, in the form of urine.*

in an extremely simplified form. Its immensely complicated natural construction may be seen in Figure 256, which represents a greatly enlarged metal model of a urinary filter; (b) is the blood vessel, (c) is the filter cup to which the urinary canal is attached in the form of a thick ball of threads. In Figures 254 and 257 it is shown as a simple loop. The true path of the urinary canal is shown in Figure 256, and with the help of the numbers (1 to 28) one can follow the course of this small labyrinth. The entire structure with all its loops is no larger than a speck of dust, and each kidney contains approximately one million such filter apparatuses. If the convoluted and twisted coil of a single filter canal is straightened out, one obtains a tube about two inches long.

The Preparation of Urine. The branch of the blood vessel which enters the filter is thicker than the branch which leaves it [Fig. 257]. Thus there is an increased pressure within the filter due to congestion. The urinary filter is a high-pressure apparatus. In the course of a day each cup filters 0.3 cubic centimetres of water from the blood. For the two million kidney filters the total quantity is 60 quarts. The human kidneys are indeed industrious! Of these 60 quarts only 1 to 2 quarts are excreted. The greater part of the filtered water is reabsorbed by the blood vessels which surround the tube through which it passes. The wall of the urinary canal is covered with cells—15,000 in each filter coil, 30 thousand million in the two kidneys—and each cell is built like the structure shown in Figure 255. The cell extends approximately 100 suction tubes (above) into the urinary canal, through which the "provisional" urine is slowly flowing, and absorbs water and probably other components from it. Within the complex cellular structure these products are treated in a manner of which we are still ignorant. Then they are carried through the thick cell tubes of

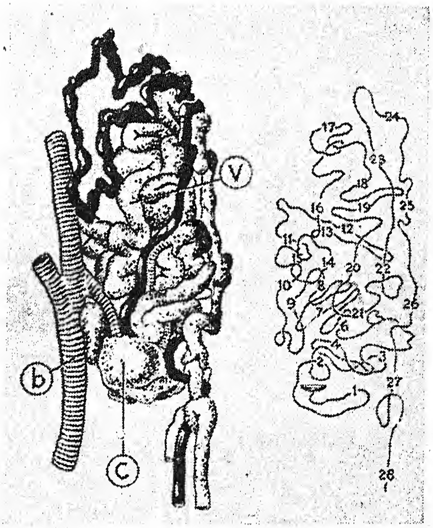


FIG. 256. *The complex structure of a urinary filter. The figures trace the maze-like path of the canal (V); (b) is the blood vessel, (c) the filter capsule.*

the external half of the cell (below) to the blood vessels which surround the outer wall of the urinary canal. The convoluted urinary canal is thus a kind of "urinary intestine" in which the provisional urine produced by the filter apparatus is subjected to a digestive process. Fifty-nine of the sixty quarts pass through the wall of the urinary intestine back into the blood; the remainder is carried off by the ureter as a kind of "fæcal matter," and passes through it into the bladder.

Although a great deal is known

about the process of urinary secretion it is still impossible to give a full and detailed explanation of this function.

Collecting Tubules, Kidney Pelvis, and Ureter. The drops of urine that leave the convoluted urinary canals [Fig. 258 (v)], collect in ducts, called collecting tubules (a). These ducts are arranged like the spokes of a wheel and converge at the centre of the kidney, where they open into the pelvis of the kidney (I). In Figure 259 one recognizes the pyramids of the converging collecting tubules (a) in the sectioned kidney, and sees how the tips of the pyramids extend into the openings of the renal pelvis (I). The branches of the renal pelvis unite to form the two ureters (u), which pass downward as fine tubes, about 10 inches in length, along the posterior wall of the abdominal cavity, and open into the urinary bladder at (d).

Kidney Diseases. As in most other diseases, heredity plays a part in the origin of kidney disease. The members of some families tend to become victims of kidney disease, while in other families the members remain untouched despite the fact that they put a great strain on their kidneys.

Poisons and Toxins

The habitual misuse of coffee, tobacco, and alcohol injures the kidneys, like the habitual administration of poisons, such as lead which painters and printers inhale daily for hours or ingest when they eat their food with dirty fingers. Since most poisons, both those artificially introduced as well as bacillary toxins, are excreted by means of the urine, the kidneys are particularly exposed to poisons and infectious diseases. Scarlet fever, diphtheria, and tonsillitis may cause inflammation of the kidneys. After every attack of tonsillitis, especially in children, the urine should be examined to see whether the kidneys have been damaged. On account of the narrowing of the small blood vessels in cases of arterio-sclerosis and high blood-pressure, the filters do not receive enough blood and shrink. As a result the entire kidney contracts and becomes smaller (a "contracted kidney").

Kidney Disease

The Testing of Renal Function. The existence of kidney disease can be established by examining the urine and testing renal function. In order to test the function of the kidney a blue dye is injected under the patient's skin, and the physician observes by means of an electrically illuminated apparatus (cystoscope), which is inserted into the bladder, how long it takes for the dye to appear in the bladder with the urine. With the aid of this apparatus, in a healthy kidney the blue dye can be seen shooting out of the ureteral orifices in blue clouds after approximately fifteen minutes. If the kidney is diseased it takes longer for the dye to appear, or it may not appear at all.

Urinary Casts. Like every other organ the kidney loses old cells uninterruptedly. These cells can be seen by examining the urine microscopically. A sick kidney loses more cells than a healthy one. If the urinary canals are inflamed they exude an inflammatory mucus, or even pus, just like the nose in case of a cold, or the bronchi in bronchial catarrh. These clots are pushed through the narrow tubes and appear in the urine as casts of these

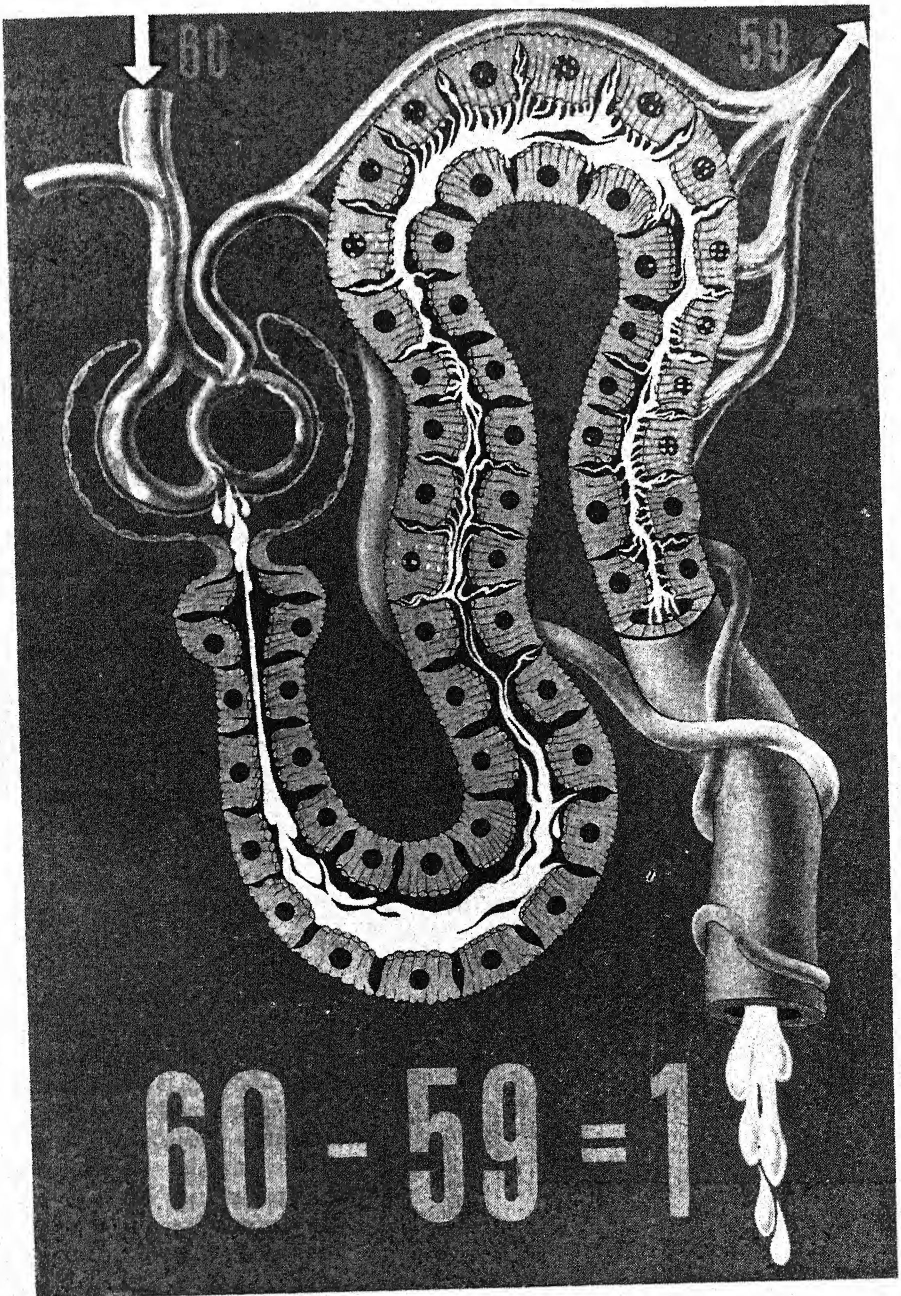


FIG. 257. *A simplified drawing of the mechanism of urinary secretion. On the left are the coils of a kidney filter. Of the sixty quarts of urine secreted daily, fifty-nine quarts are reabsorbed in the urinary canals (Upper Right). Only one quart enters the bladder.*

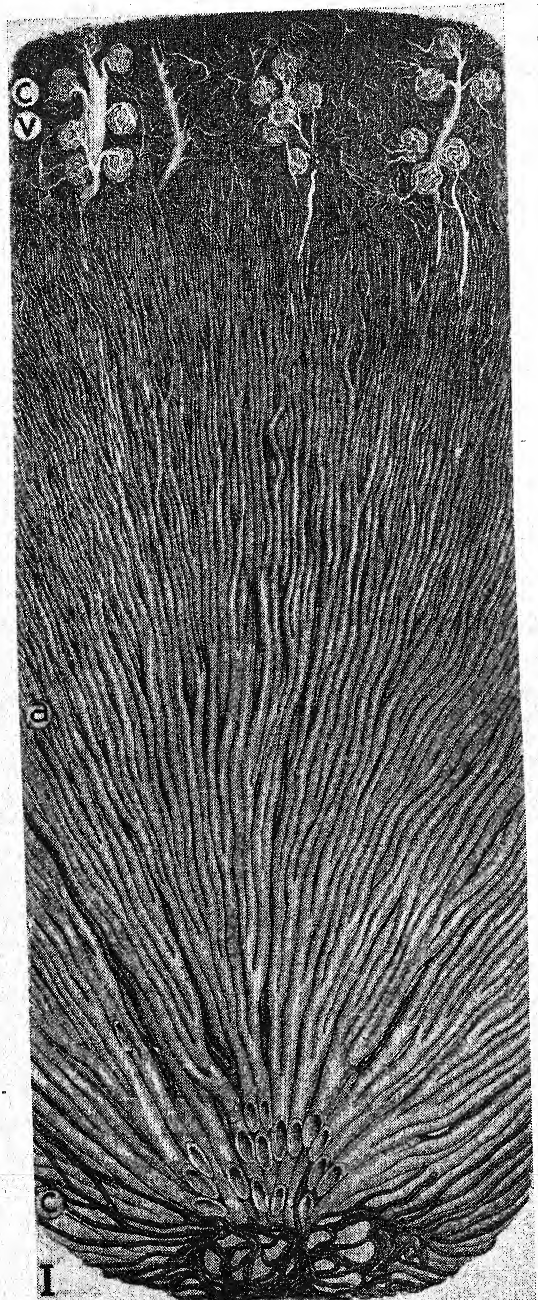


FIG. 258. *The collecting tubules (a) conduct the urine from the canals (v) into the kidney pelvis (I).*

tubes, having the form of elongated cylinders. The type of casts observed — namely, whether they consist of albumen, cells, or blood— permits the doctor to draw conclusions as to the nature of the kidney disease.

Kidney Stones. If the salts in the urinary fluid remain undissolved, they are deposited either as tiny particles (gravel) or as larger concretions (stones). Depending on their position, the latter are called kidney stones, ureter stones, or bladder stones. They may consist of uric acid calcium salts, oxalic acid, or mixtures of these substances. Such stones can be as smooth as flint or as jagged as coral. Furthermore, they can lie unnoticed in the kidney for decades; on the other hand, they can also produce intense attacks of pain, so-called renal colics.

The Urinary Bladder. The urinary bladder is a balloon of muscle fibres lined with a mucous membrane [Fig. 259 (d)]. Under normal conditions it can hold about one quart of fluid, but owing to the ingenious interlacement of its fibres it is able to expand considerably without bursting. Within the wall of the bladder the nerves end in delicate little bulbs that inform us concerning the degree of tension of the muscles, and in this way of the fullness of the bladder. We become conscious of the bladder tension as a

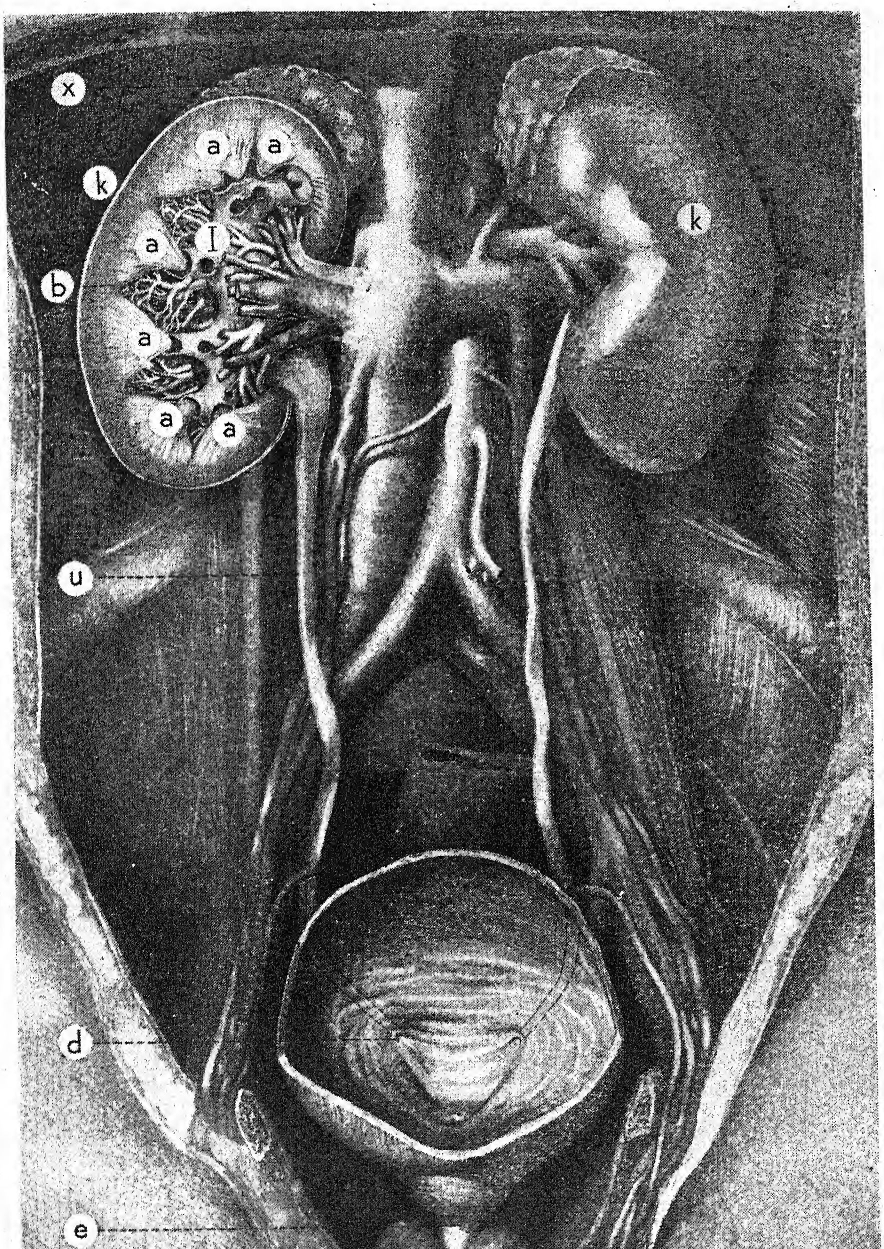


FIG. 259. *The human urinary system. One of the kidneys (k) is shown in section, revealing its complicated structure. Note the collecting tubules (a), leading into the kidney pelvis (I). The two ureters (u) can be seen opening into the bladder (d); through the urethra (e) urine leaves the bladder; (x) indicates the adrenal glands.*

desire to urinate. If one steps on a cold stone floor with bare feet, or if the feet are dipped in cold water when one goes swimming, the bladder musculature contracts [Fig. 242], and one has a sudden desire to urinate, even if the bladder is not very full. Similarly, when the mucous membrane is inflamed, the nerves constantly report a desire to urinate, even when the bladder is not full.

Complex Waste Products

Urine. The urine contains many different constituents, among them extremely complex compounds. The specific gravity of the urine, which is determined by means of a hydrometer or urinometer, indicates the quantity of solid substances contained in it. The specific gravity of urine varies between 1,003 and 1,040. If the number above 1,000 is multiplied by 2.3 one obtains the quantity of dissolved substances contained in one quart. One quart of urine having a specific gravity of 1,020 contains $20 \times 2.3 = 46$ grammes of solid substances. The kidneys excrete daily about 50 grammes of solid matter.

The Colour of the Urine. The colour of the urine is determined by a mixture of yellow, green, red, and pink pigments, of which the yellow urochrome is derived from protein, the green urobilin from bile, and the various red and pink pigments from other sources.

Urea. The ammonia derived from the amino acids is excreted as urea, which is the most important of the colourless constituents of the urine. The quantity of urea is an indication of the amount of protein used up by the body in the course of a day. The kidneys excrete daily approximately 30 grammes of urea, so that it comprises two thirds of the solid matter in the urine. One can therefore describe urine as a 3-per-cent solution of urea. Urea is synthesized in the liver from the ammonia of the amino acids and the carbon dioxide of the blood. If a solution of ammonia and carbon dioxide is conducted through the vessels of a liver immediately after removal from an organism, urea is contained in the solution when it leaves the liver. Urea was the first organic compound to be prepared in the laboratory. With the artificial production of urea, approximately a hundred years ago, began the triumphal career of synthetic chemistry, to which we owe many medicinal drugs used at present, such as aspirin, amidopyrin, adrenalin, veronal, salvarsan, and many others. Urea can easily be rendered visible. A drop of urine is placed under a microscope and a woollen thread is placed in the urine so that both ends of the thread project out of the drop. If nitric acid is now dropped on the free ends of the thread, it is carried by capillary action into the drop of urine, and crystals of urea combined with nitric acid become visible.

Bacteria in Urine

If urine is permitted to stand for some time, a penetrating, acrid odour arises from it. Bacteria from the air fall into it, among them the ubiquitous, spherical *Micrococcus ureæ* and the rod-shaped *Bacillus ureæ,* which live on urea. At the same time ammonia is liberated, giving rise to the well-known penetrating odour of standing urine, which also arises from dungheaps. The ammonia which remains in the urine combines with acids or alkalis to form either ammonium urate [Fig.

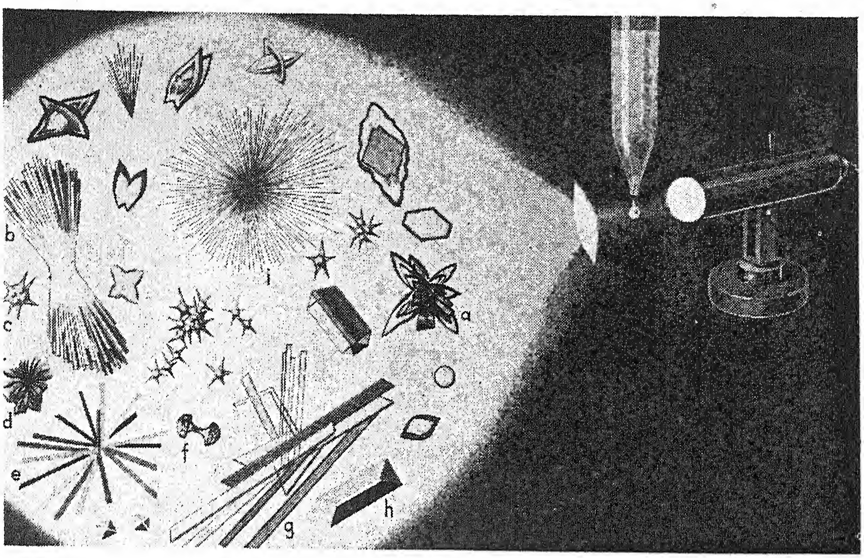
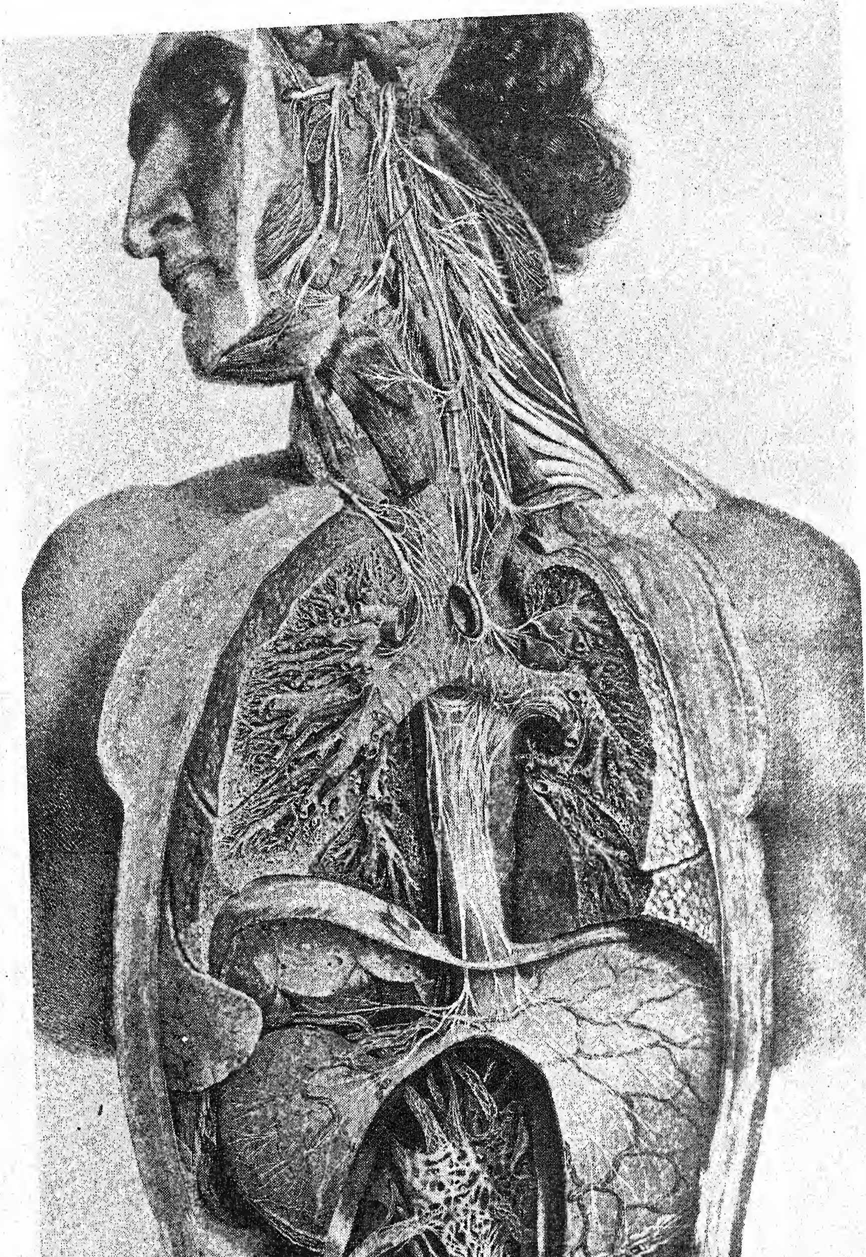


FIG. 260. *The world within a drop of urine. The crystals revealed in this beam of light are: Above (a—b), uric acid; (c) ammonia; (d) creatin; (e) benzoic acid; (f) oxalic acid; (g) calcium sulphate; (h) ammonium phosphate; (i) the amino acid, leucine*

260 (c)] or ammonium phosphate (h).

Uric Acid. In addition to urea, the metabolism of the most complex protein compounds, particularly those present in a cell nucleus, gives rise to uric acid. If a person consumes a great deal of meat, he excretes a large quantity of uric acid. All the crystals shown in Figure 260 between (a) and (b), along the upper border of the light beam, are crystals of uric acid. When the body is in a febrile state, many cells are destroyed, and as a result the urine of febrile patients contains excessive amounts of uric acid, which is deposited in the form of red grains on the floor of the vessel. "My urine looks as if there is blood in it," a feverish patient may tell his doctor, but it is not blood, only a sediment of uric-acid crystals.

If one eats spinach, lettuce, or cabbage, oxalic-acid crystals may be found in the urine (f). After eating apples, pears, figs, and cranberries, benzoic acid, which is contained in these fruits in the form of hippuric acid, appears in the urine (e). If one has partaken of foods having a high sulphur content, such as eggs, lentils, peas, beans, and radishes, calcium sulphate is found (g). Upon dropping a few drops of zinc chloride into some urine, one observes the appearance of remarkable structures that resemble fungous growths on trees. These are crystals of creatin, which is produced as a result of muscular activity (d). If urine is mixed with sulphuric acid, a few drops of chloroform are added, and a strong oxidizing agent such as chloride of lime is then added, a beautiful blue colour appears, due to the formation of indigo, the famous dye which was formerly obtained from India. In this manner many interesting experiments can be made with urine



THE VAGUS NERVE

FIG. 261. *The vagus nerve is a vast network of neurons passing downwards from the brain. This nerve has a "braking" influence upon the activities of the organs.*

VIII: THE NERVOUS SYSTEM

CHAPTER XXXIII

The Nerve Cells

THE NERVE CELL. NISSL GRANULES. A DAY IN THE LIFE OF A NERVE CELL. THE NERVE FIBRE. NEUROGLIA. SPEED OF THOUGHT. THE PERSONAL EQUATION. PSYCHOTECHNICS. SENSORY NEURONS. MOTOR NEURONS. THE CONNECTING NEURON. THE REFLEX.

THE function of the cells of the integument is to protect the body. For this purpose they have specialized in two directions. The one group has developed the ability to react to stimuli; these cells have become "receptors," which inform the body of conditions in the outer world; the others have strengthened themselves and cover the body with a protective horn layer. The cells of the first group are the nerve cells; those of the second group have become the skin cells.

The reporting cell is originally situated on the surface of the skin among its sisters, and transmits the stimulus that it receives into the depths by means of a protoplasmatic thread. Cells that are situated in the skin and transmit stimuli to the deeper parts are called cutaneous sensory cells.

Buried Cells

Lower organisms have no other nerve cells but these outer ones, and even in man they have survived in certain parts of the body—namely, in the protected oral and nasal cavities. In the course of evolution most of the cutaneous sensory cells have withdrawn into the depths and are in contact with the outer environment only by means of their extended protoplasmatic processes. These buried sensory cells are the nerve cells.

Watchmen Cells

The sensory cell in the surface skin corresponds to the ancient watchman who kept his vigil on the castle wall. The deeply buried sensory cell is analogous to a modern listening post and telephone switchboard, situated far under the earth in a concrete room, where, by means of receiving apparatus and conducting wires, reports from the outer world are received and transmitted. The human nerve cell is certainly no greater marvel than the liver cell, which is capable of carrying out simultaneously twenty different chemical reactions of the most complicated kind, or the sperm cell, which bears the hereditary factors of an entire human family in its chromatin granules. However, of all

the cells in the human body it undeniably exhibits the most interesting structure [Fig. 262]. At one end it bears an antenna (a), with the tips of which it receives stimuli. Some nerve cells are surrounded by a sheath (b) which is continuous with the covering of the nerve fibre belonging to the cell. The typical nerve cell is large, and has a large vesicular nucleus (d) with very little chromatin. Within the nucleus are mechanisms of various kinds, the details of which are still unknown.

Fuel System

Around the nucleus passes a system of tubes (e) which is called the Golgi apparatus, after its discoverer. Perhaps it is through these tubes that the nucleus absorbs from the cytoplasm the substances which it uses for fuel. These substances accumulate around the nucleus and disappear during cellular activity.

Nissl Granules. The fuel substances of the nerve cell can be seen under the microscope in the form of the so-called Nissl bodies. These are angular masses of granular material that have an affinity for certain aniline dyes. The Nissl granules change in size and number with the physiological condition of the cell. Thus it is found that nerve cells which have been fatigued by prolonged activity show the Nissl bodies becoming disintegrated. Indeed, they may even disappear for a time from the cell. A similar result is found to occur after the action of poisons which especially affect the nervous system. The Nissl granules appear to consist chemically of nucleoprotein. They also contain organically combined iron.

A Day in the Life of a Nerve Cell. In the morning when an individual awakes, his nerve cells are filled with Nissl bodies. He leaves his bed like a locomotive leaving the engine-house; the tender is filled to the very edge with coal. The "nerve coal" (the Nissl bodies) provides the material from which the individual draws his nervous energies. With every movement, with each state of excitement, with every sense impression, and with each thought a trace of "nerve coal" disappears from the cells of the brain, and in the course of a day the nerve cells become depleted. During sleep the cells are refilled; nutritive materials pass from the blood into the cells, where they build Nissl bodies.

The Life History of a Nerve Cell. The process just described goes on continuously for years and decades. Every morning after awakening, the cleaned and newly filled motor begins to whir once more, and continues to work for fourteen, sixteen, or eighteen hours. Isn't there ever a breakdown in the machine, a torn cable, a flat tire, or a worn-out bearing? Is it a perpetual-motion machine? No, it is not! The ageing process actually begins at the age of ten; the pineal gland is the first part of the nervous system to be affected. Between twenty and thirty the reactive capacities of the individual diminish markedly. At the age of forty the signs of the ageing process in the nerve cell become anatomically demonstrable.

Insulated Cables

The Nerve Fibre. From the antenna of the cell delicate fibres, called fibrils, pass through the protoplasm and spread out within the cell in the form of finely ramifying networks [Fig. 262 (f)]. In one corner these fibrils unite to form a cable,

which carries the impulses arising from the cell and is known as a nerve fibre (g-n). A nerve fibre is probably the best constructed cable in the world. In the centre run the conducting wires, the fibrils (f, g). Each fibril is embedded in an isolating material, and all the fibrils are combined to form a bundle. The bundle is contained in a sheath (h), consisting of conically shaped funnels that are ingeniously fitted into one another. These funnels are filled with an isolating fat, having the consistency of butter (i). This fat, which is called myelin, consists of complex proteins and phosphorous fats. In our high-tension machines oil is used as an isolating material; nature anticipated this trick by millions of years by creating myelin as an isolating (or insulating) substance for the nerve fibres of higher organisms.

Neuroglia. On the outer wall of the nerve fibre, cells are to be found at regular intervals. They are known as neuroglia, or glia cells (l). They are to be found throughout the entire nervous system. They connect the nerve cells with the blood vessels, and apparently transport various substances from the blood to the functioning elements of the nervous system. When the nerve fibres grow out of the brain and spinal cord in the developing embryo, the glia cells wander along with them. They are situated on the outer walls of the nerve fibres like plant lice on flower stems, but they do not suck off any nutritive materials; on the contrary, they bring them to the

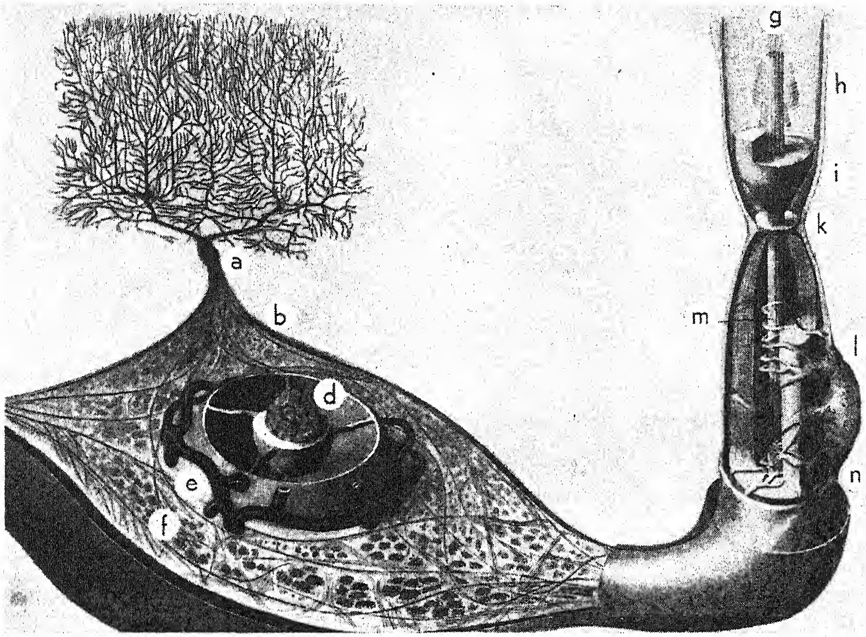


FIG. 262. *A nerve cell and its cable. Stimuli received by the antenna (a) pass along the fibrils (f) into the complex "cable," or nerve fibre (n-g). The tubes at (e) form the so-called Golgi apparatus; (d) is the cell nucleus. At (l) is a glia cell.*

fibres. Each glia cell takes care of an area of $\frac{1}{10}$ square millimetre. A nerve fibre running from the spinal cord to the tip of a finger is covered by approximately 5,000 glia cells. The spheres of the various glia cells are separated from one another by a constriction of the cable. At the point of constriction a plate has been inserted into the cable which apparently serves as a support (k). The glia cell has innumerable processes (m) that pass through the isolating layers to the cables, so that the latter are surrounded by them. The glia fibres consist of a hornlike substance. If a nerve fibre is boiled, the isolating fat melts, but the horn framework of the glia cells remains.

The Speed of Thought In earlier times the rapidity with which an impulse was conducted along a nerve fibre was considered the quintessence of speed, hence the expression: "quick as thought." This idea has been superseded, however, by the accomplishments of modern technology; an aeroplane flies faster, not to mention the achievements of the telephone, the telegraph, and the radio. A nerve impulse is propagated at a speed of approximately 228 feet per second or 156 miles per hour. If a giant were stretched out over the earth so that his feet lay in the water at the southern tip of South America, at Cape Horn, while his head lay in Alaska, the bite of a shark that had attacked him on Sunday morning would first be perceived by his brain on Wednesday evening. And should he now wish

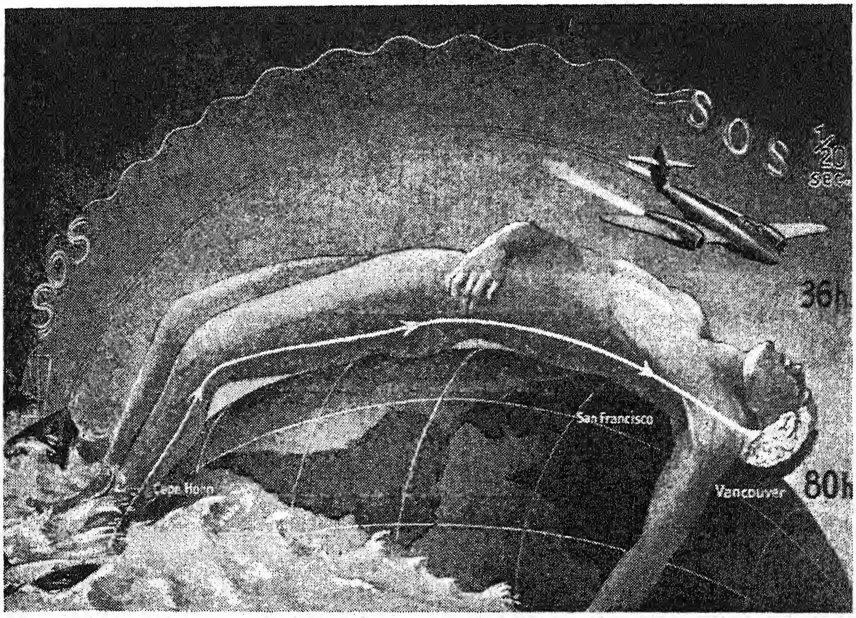


FIG. 263. *The speed of thought is outclassed by the performance of some modern discoveries. A giant extended over the globe from Cape Horn to Alaska would not feel that his feet were being bitten by a shark until eighty hours had elapsed. An aeroplane would cover this distance in thirty-six hours, radio waves in $\frac{1}{20}$ second!*

to withdraw his foot "rapidly" from the water, his desire would avail him little, for it would take until the end of the week before the volitional impulse would have reached his foot. After having withdrawn his foot, he would still have a feeling on Sunday, Monday, and Tuesday that his foot was in the water and was being bitten, for it would take so long before he had realized the fact that the foot had been drawn up on dry land [Fig. 263]. The sun is separated from the earth by a distance of 93 million miles. Books on astronomy try to give the reader some idea of the magnitude of this distance by means of the following comparison: If a child were born that kept its hand on the sun, it could live undisturbed for the rest of its life. It would never feel any pain since it would take 120 years for the pain sensation to travel from the sun to the earth.

"As Slow as Thought"

If a thought were produced at eight o'clock in London and transmitted through a nerve, it would pass through Paris at ten o'clock and arrive at Zürich at two o'clock. Not only the telegraph, but even an aeroplane departing at the same time would bring the thought much more rapidly to its destination.

The Personal Equation. That thought processes and all other nervous reactions do not occur with lightning speed but take place with relative slowness was discovered by astronomers and not by physicians. At the end of the eighteenth century an assistant was discharged from the famous observatory at Greenwich because his measurements could not be brought into correspondence with those of the director. It was also observed at other observatories that there were deviations among the time determinations of various astronomers, and that these deviations were always alike. Thus all the observations of stellar time made by astronomer A differed from those of the equally reliable astronomer B by $\frac{1}{6}$ second.

Bessel's Discovery

The celebrated German astronomer Bessel, who first determined the distance of a fixed star, came to the conclusion that these differences in the determination of time were due to the fact that the velocity of propagation differs in the nerves of different people. The nervous system of each individual has a characteristic current velocity. The time loss that must be ascribed to nerve conduction and deducted from the calculations of the astronomer is known as the personal equation. Every individual possesses a characteristic personal equation.

Psychotechnics. The personal equation of the astronomer became the starting-point of an entire science called psychotechnics. When anyone applies for a job as a bus-driver or an aviator, the applicant may be given a psychotechnical examination. He is taken into a room that a person of the fifteenth century would look upon as a torture chamber.

Assessing Nervous Reaction

Supposing the applicant wants a job as a chauffeur, he is seated in a model motor car while red, yellow, and green light signals are flashed upon a screen before him. When red appears he must apply his brakes; when the green light flashes he must start the car. The time

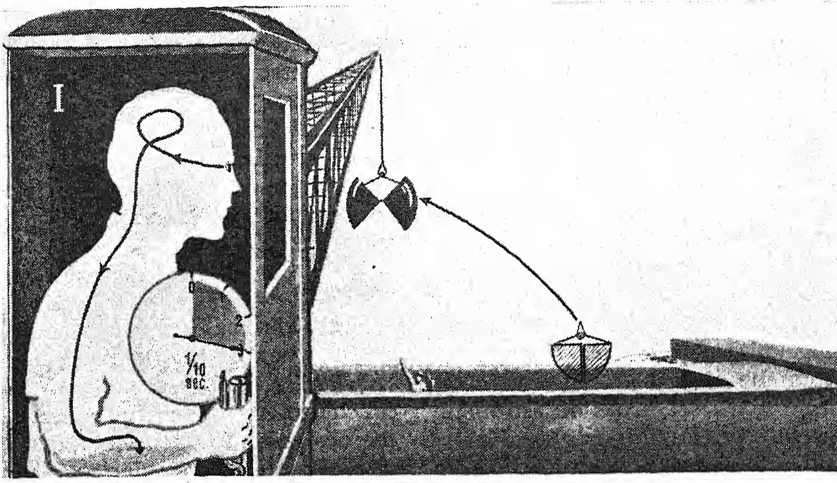


FIG. 264. *The Speed of Reaction (I). In an alert and intelligent person the reaction eye-brain-arm (denoted by black line within the body) occupies $\frac{3}{10}$ second. A man of this type employed, for example, as a crane-driver can direct the scoop of his crane to its goal along the shortest possible path, without loss of time.*

that elapses between the appearance of the red light and the application of the brakes is determined in tenths of a second by a special apparatus. At a stop signal given by a gramophone, the applicant must stop the car. He is further examined to determine how he behaves when blinded by a very bright light, and whether he can drive safely in fog.

Exhaustive Tests

He is tested to determine how rapidly his eyes become accommodated to darkness, by finding how long it takes him to find a push-button in the dark; and he must state whether the surface upon which he is seated is inclined to the right or to the left. Electrocardigram, pulse count, and blood-pressure determinations furnish indications as to the courage of the applicant. The apparatus used for these determinations registers the results with inexorable objectivity; it indicates how much he trembles and how rapid his pulse becomes when a suddenly punctured tire makes a loud noise, or when the image of a runaway horse dashing directly towards him is flashed upon a screen.

Psychotechnic investigations have brought to light the following facts:

1. The faculties of men differ greatly. Some people react to signals in $\frac{2}{10}$ of a second, others in $\frac{4}{10}$ of a second; while intellectually inferior individuals require $\frac{1}{2}$ a second or more.

2. These faculties are not equally distributed for all types of reactions; rather, each person is better equipped for certain kinds of reactions and not so well endowed for others. One individual achieves his best performance in the optical test, another in equilibrium determinations, while a third is at his best in tests of courage. This is a well-known fact in athletics. There are tennis players who are stronger on the de-

fence, while others are better on the attack; players with short reaction times are well suited for play at the net, while more "cool-headed" players exhibit their strong points in the rear of the court. The best performances are achieved only when the right person is put in the right place.

3. The reaction speed varies with the kind of stimulus. The response to sound is more rapid than to light. People react more rapidly to bright light signals than to dull ones. We react more slowly to red than to white because the retina of the eye, like a photographic plate, requires more time for the assimilation of red. Unpleasant stimuli produce a more rapid response than pleasant ones. We all know that one exhibits aversion to a bad smell more quickly than pleasure at a pleasant odour. Something bitter is spat out with a speed never achieved in recognizing a taste that is accepted as pleasant.

4. Bending movements are executed more rapidly than stretching movements, because a crouched position is more important for the protection of life than an erect one.

5. Reaction speed varies with the nervous condition. A rested individual reacts more rapidly than a tired one. Most railway accidents occur during the last hours of a particular worker's shift. For this reason working time is sometimes divided by rest periods so that the workers do not work long stretches without a break.

Why Practice Makes Perfect

6. The reaction time may be shortened as a result of training. The more frequently a nerve path is used, the more rapidly does it conduct. Above all, connections between the nerve cells are made more rapidly.

The results of psychotechnical investigation have been applied practically in vocational guidance and

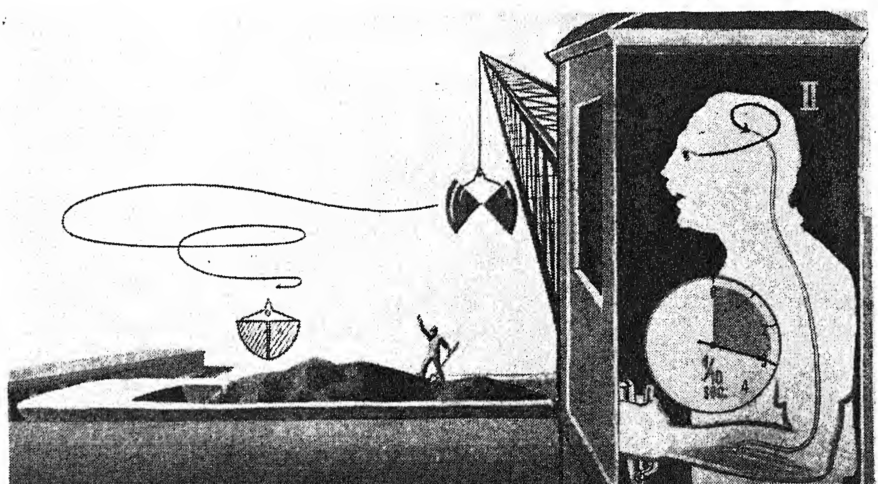


FIG. 265. *The Speed of Reaction (II). In a less alert person the nerve impulse takes more than $\frac{3}{10}$ second to leave the brain. A crane-driver of this type directs his scoop along a zigzag path, losing time and performing less work. Over a long term, the waste of time and energy may be considerable.*

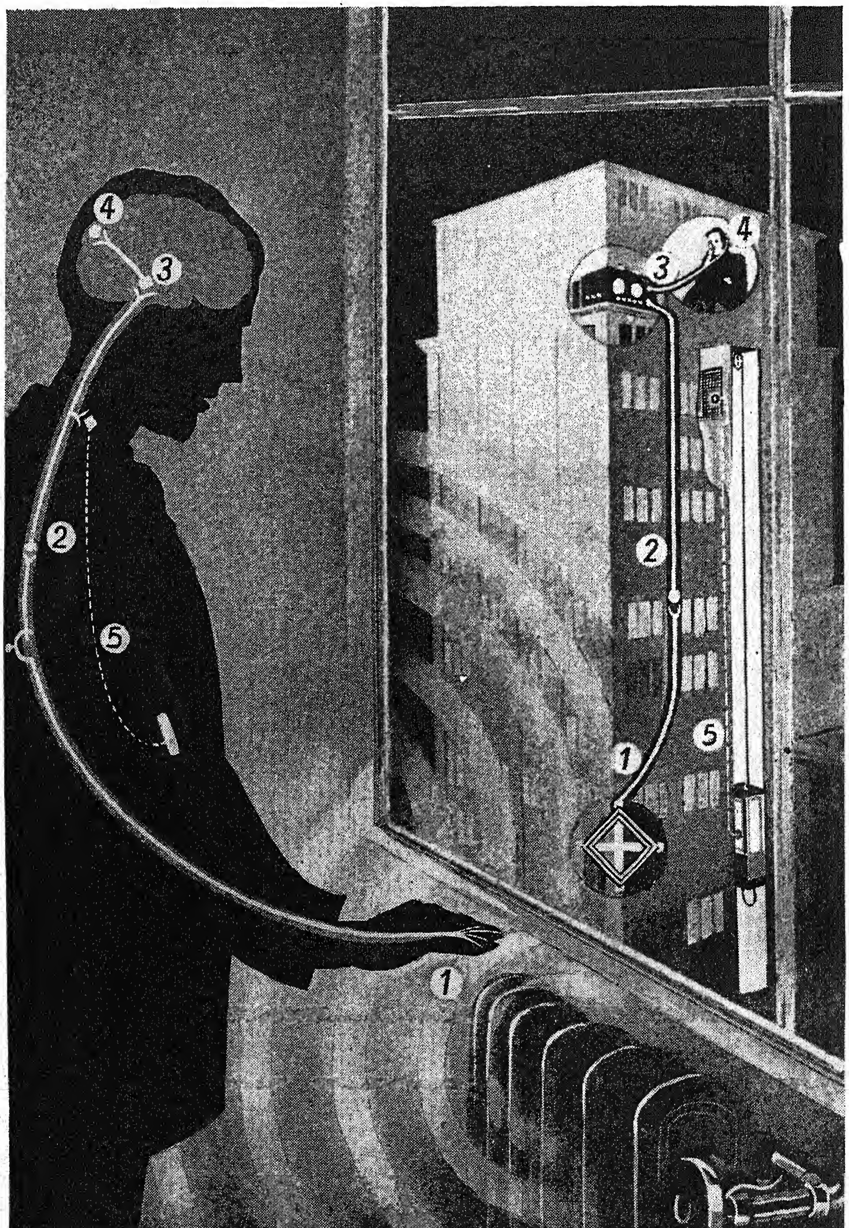


FIG. 266. *The neurons, or segments of the nervous system, may be compared with the component parts of many electrical appliances. (1) Sensory neuron (radio aerial); (2) conduction neuron (conducting wire); (3) receiving neuron (radio apparatus); (4) sensory cerebral neuron (man listening); (5) motor neuron (elevator switch).*

employment psychology. The significance of psychotechnic examinations for occupational and economic life may be illustrated by the cases shown in Figures 264 and 265.

Nerves and Economics

Two men work in a harbour as crane-drivers. Driver (I) has a rapid reaction time and is a good judge of distance. He is able to translate a visual impression into a movement of the crane in 1.6 seconds. For a complete "trip" from the bottom of the barge to the loading place and back he needs two minutes, travelling at the same time through a distance of 36 feet. In twenty years he has made one million trips with his crane over a distance of 9,936 miles and loaded 600,000 tons. His colleague (II) has a slow reaction time and is a poor judge of distance. Instead of two minutes for a complete "trip" he needs three, while in the course of each trip his crane travels through a distance of 52 feet instead of 36. In twenty years he has loaded only 400,000 tons while his crane has travelled over a total distance of 12,420 miles. In terms of economics this means that he must be paid not for twenty, but for twenty-six years; in addition he has taken his heavy crane for a trip of 2,484 miles at the expense of his company!

Occupational Misfits

This man, who should never have become a crane-driver, is one of the hundreds of thousands who have chosen an occupation at random without any test of their abilities, and now perform their duties as best they can. Vocational psychology, recognizing this fact, rejects applicants whose abilities do not measure up to the standards required for a certain occupation. In doing so, however, it takes into consideration not intelligence only, but also special aptitudes.

The Neuron. Nerve cells and fibres can easily be made visible. Silver chromate or silver bromide, the same chemicals that are used for photography, also form compounds with the fats of nerve tissue. If a piece of tissue is saturated with silver solutions and exposed to light, the nerve tissue is "photographed" and the silhouettes of the cell fibres become visible. Now one recognizes that each cell together with its processes forms a completely independent unit called a neuron. The nervous system is composed of anatomically independent nerve cells that are connected physiologically at junction points known as synapses.

Modern Research

This neuron theory constituted the starting-point for the magnificent successes of modern research on the nervous system. It was recognized that the nervous system is a relay system of individual units, the neurons, connected by means of the synapse or junction point. The synapse is not a fibrous connection but a point of contact at which the nervous impulse is relayed from one nerve cell to the next. Recognition of this fact at once made clear many of the topographical problems of neurology, and, above all, of the diseases of the nervous system.

The Four Types of Neurons. There are four chief types of nerve cells, or, more accurately, nerve units, neurons [Fig. 266].

1. Sensory neurons, which receive the stimuli of the outer world, such as heat, cold, light, and pain, and

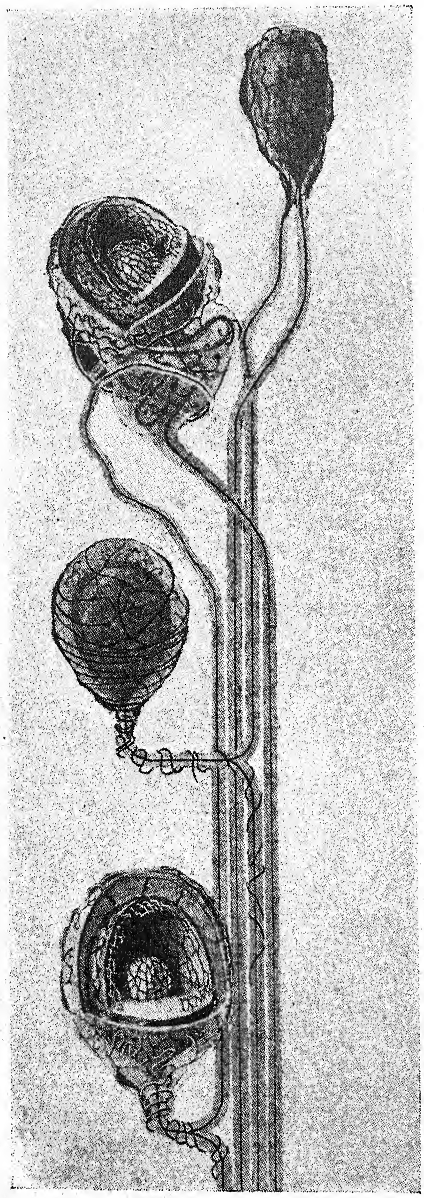


FIG. 267. *Sensory cells. Surrounding each cell are delicate nerve fibres which convey external stimuli to the cell. All sensory cells communicate with motor cells, which transform sense impressions into action impulses.*

conduct them to the interior of the body (1).

2. Motor neurons, which receive the stimulatory impulses from the sensory neurons and respond to them by sending a nerve current to the mechanical apparatuses of the body, the muscles and the glands, causing these organs to react reflexly (5).

3. Connecting neurons, intercalated in order to conduct stimuli over greater distances, or to transmit a stimulus from one cell to several other neurons (2 and 3).

4. The cortical neurons of the cerebrum, in which the stimuli of the outer world, such as cold, heat, pain, etc., are brought to the individual's consciousness (4).

The Sensory Neurons. In Figure 267 we see a number of sensory cells. These cells differ in their structure from the motor neurons. Externally they are generally surrounded by nerve fibres that end as fine filaments at the cell or are wound around it in the form of spools.

Reporting Fibres

These fibres apparently transmit external stimuli to the cell, thus keeping it constantly informed concerning the state of tension in the muscle fibres, the temperature of the skin and the blood, the position of the hair, etc. All sensory neurons communicate with other neurons at their central terminations. Each sensory neuron has a number of such connections.

The Motor Neurons. Having received the stimulus by means of its long afferent fibre, the sensory cell re-works it in some manner as yet unknown to us and transmits it by means of a filament contact to a motor cell. This cell transforms the

received stimulus into an action current which it sends through its long efferent nerve fibre to the organ that is to respond to the stimulus—for example, to a muscle that contracts, or to a gland which secretes [Fig. 266 (1), (2), (5)].

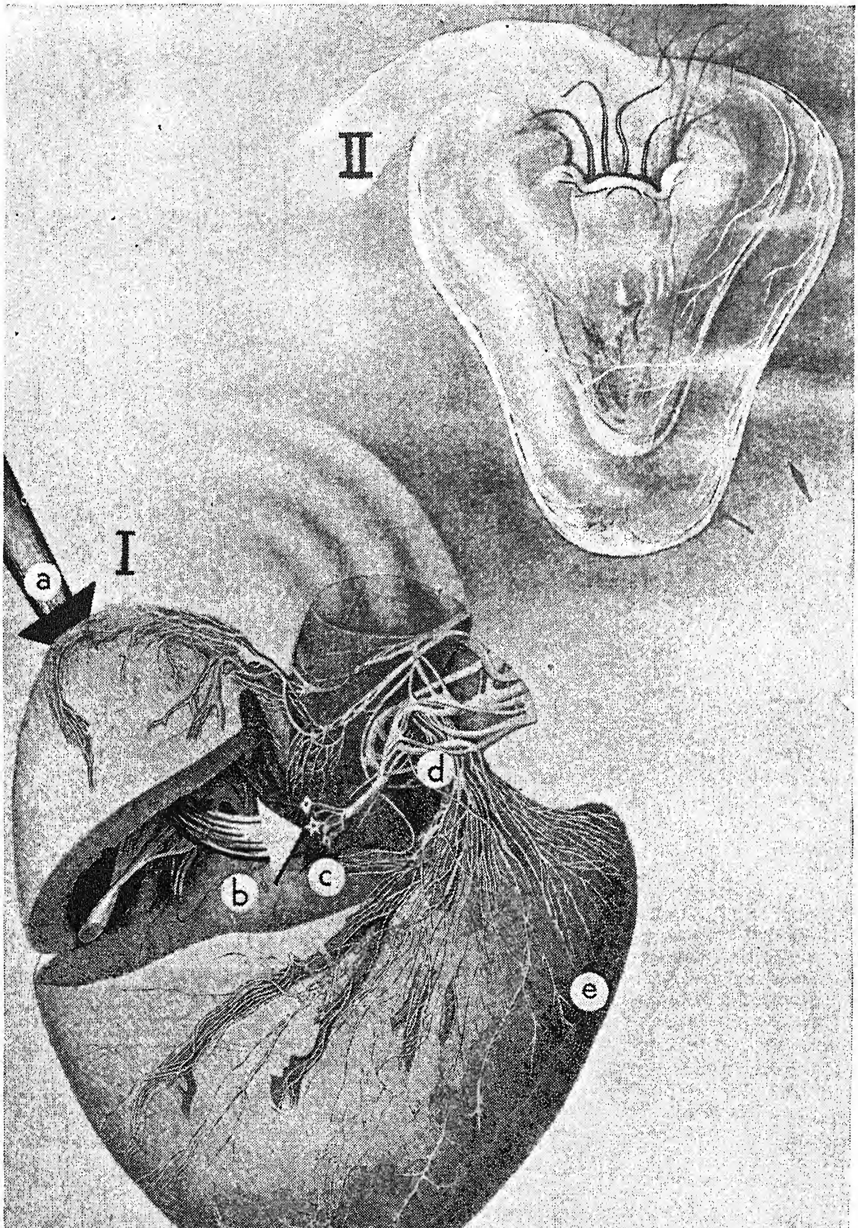
The Connecting Neuron. If the sensory and motor cells are not in direct contact, a connecting cell (an internuncial neuron) links them by means of its processes. The cortical cells [Fig. 266 (4)] of the brain lie high above all the other cells like Alpine huts above the valleys, and are accessible to stimuli only through connecting neurons that conduct the stimulatory currents through the spinal cord to the brain cells (2-3).

Cause and Effect

The Reflex. The body usually reacts at the point where it is stimulated. If a finger is pricked with a pin, the hand is at once withdrawn; when a foreign body enters the eye, it is immediately closed. The nerve stimulus passes from the periphery of the body to a sensory cell in its interior, where it is transmitted to a motor cell and returns to the point of stimulation as an action current. It travels like a ray of light reflected by a mirror; for this reason the entire process of stimulus reception and stimulus response is known as a " reflex."

Demonstrating the Reflex

One can quite easily demonstrate a reflex to oneself by standing in front of a dark or partly darkened mirror and suddenly flashing a light into one's eye. Approximately three-fourths of a second later the pupil contracts. The light stimulus passed from the eye into the brain, where it stimulated a sensory nerve cell. The latter transmitted its excitation to a motor cell, which sent an action current to the pupillary muscle in order to contract the pupil and thus protect the illuminated eye. In Figure 266 the reflex path passes upwards from (1) to (2) (sensory), and returns by way of the motor neuron (5) to the arm muscle to be moved. The reflex is the simplest and most general activity of the nervous system. More than ninety per cent of all actions in the nervous system are reflex actions, and most nervous organs are reflex devices.



HUMAN HEART AND JELLYFISH

FIG. 268. *These are remarkably similar in their organization and structure (Page 391).*

CHAPTER XXXIV

The Sympathetic Nervous System

AUTONOMOUS NERVOUS SYSTEMS. AUTONOMOUS SYSTEM OF THE HEART. AUTONOMOUS NERVOUS SYSTEM OF THE INTESTINE. THE SYMPATHETIC NERVOUS SYSTEM. VAGUS AND SYMPATHETIC SUBSTANCES. SENSATION AND THE SYMPATHETIC. HYPNOSIS.

FOR the sake of simplicity we say that man has two nervous systems: the sympathetic or abdominal nervous system, and the central nervous system, consisting of the brain and the spinal cord. Actually, however, the body contains an entire series of independent or autonomous nervous systems. One of these, the autonomous system of the heart, has already been mentioned (see pages 150-151).

Cell "Targets"

The Autonomous System of the Heart. The nervous system of the heart is a typical reflex apparatus [Fig. 268 (I)]. At the point where the venous blood from the organs flows into the heart (a, b), sensory cells are located within the wall (c). Like targets in a shooting gallery they register the number of impinging carbon dioxide molecules and transmit the stimulatory impulses to the motor cells (d), which now send action currents to the muscle fibres, so that they contract (e). The cardiac nervous system is a reflex apparatus which automatically regulates the rate of the heart according to the carbon dioxide content of the blood. Owing to its autonomous nervous system, the heart is in large measure independent of the life of the body, and can be maintained alive and beating outside it. The heart exhibits remarkable similarities to such lower animals as the medusæ (II). Whoever has observed a medusa floating in the ocean, how it sucks in the water and expels it again, has seen a living model of a functioning human heart. A medusa is a "human heart" floating in the ocean; the heart is a medusa pulsating in the human breast.

The Autonomous Nervous System of the Intestine. The heart is a medusa; the intestine, a worm. In Figure 269 two sections, one of an earthworm, the other of an intestine, are shown alongside each other, and we can compare the great similarity of their nervous systems.

Earthworm and Intestine

The worm (I) receives external stimuli through receptor cells situated in its skin (a). The stimuli are then carried by afferent fibres into the worm's interior (b). Here the stimulus is transmitted to motor cells (c), and conducted through their nerve fibres to the muscles, causing them to contract (d). The body of the

worm is constructed segmentally, and each segment has its own reflex apparatus. These apparatuses are linked by internuncial or connecting neurons (b), so that the stimulus and with it the movement produced are propagated in a "vermiform" fashion.

The autonomous nervous system of the intestine is constructed in a similar manner (II), but the arrangement is the mirror image of that of the earthworm—that is, the stimuli are not received from without, but rather from within (a); the sensory receptor cells are not located internally, but externally (b); and the motor cells lie together in groups (c). The intestine is also arranged segmentally, the cell groups of each segment being connected by internuncial cells. The movements of the intestine within us resemble those of a worm, and one can best obtain an idea of the wriggling movements of the intestine by placing an earthworm, a caterpillar, or a maggot on a table and observing its movements. The intestine is a worm suspended within the body, and just as an earthworm swallows earth, the intestine gulps down food, extracts from it the nutritious elements, and expels the residue at its other end.

Activity After Death

Because it possesses an autonomous nervous system the intestine can live as independently as the heart. In slaughtered animals the movements of the intestine can be observed for many hours after death. If a piece of intestine is suspended in a warm nutritive medium, it lives for days and continues to function. If a rubber ball is placed in its upper orifice, it begins to "choke" on this "bolus" and with the rhythmic movements of the normal intestine carries it downward until it is expelled at the other end [Fig. 270].

There are many autonomous nervous systems like those of the heart and the intestine. Most of the organs probably have their own nervous systems, but they are not yet known in detail, because the other organs are not as free and mobile as the heart and intestine.

Mutually Opposed Nerves

The Sympathetic Nervous System. The greatest of these autonomous systems is that comprising the sympathetic and the vagus, a tremendous network of neurons, which can be untangled only with great difficulty. Spreading downwards from the brain to all the viscera and all the tissues, it extends to the most remote parts of the body, to the skin of the fingertips and the capillaries of the soles of the feet. So far no one has succeeded in achieving ultimate clarity regarding the organization of this gigantic nerve structure. Figure 261 shows the chief ramifications of one part, the vagus, and Figure 271 those of the other, the sympathetic. The directing cells of this dual system are situated, in part, in the depths of the brain as the metabolic centres that have already been mentioned: the respiratory centre, the water centre, temperature centre, thirst and hunger centres, the vasomotor centre for the regulation of vascular tension and blood distribution, etc. Another group of cells is located in the ganglia alongside the spinal column or in the trunk and neck in the form of such nerve structures as the carotid plexus, the solar plexus of the

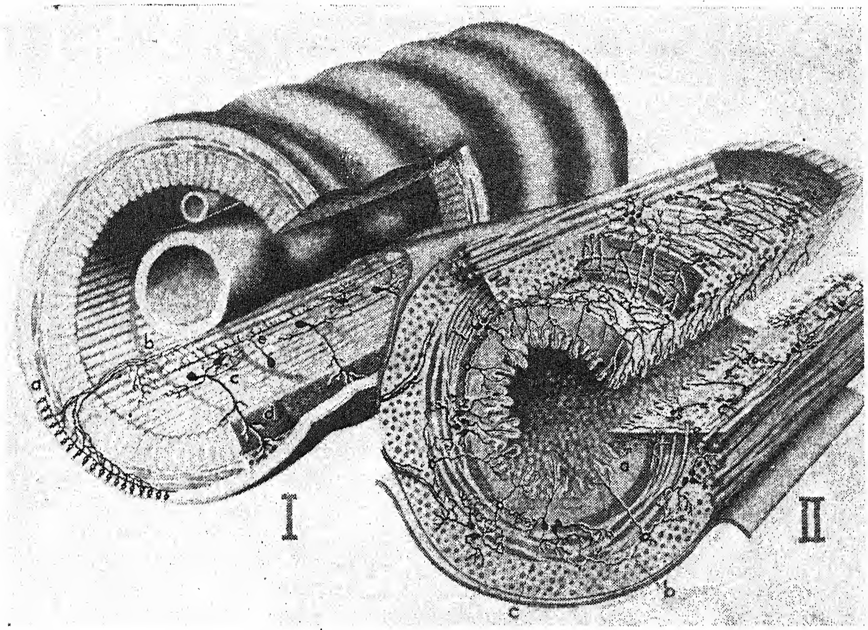


FIG. 269. *An earthworm (I) and the human intestine (II) present the same fundamental features in their nervous organization. Hence, their reactions are very similar.*

epigastrium, and innumerable other ganglia in other parts of the trunk. Ganglia, or nerve nodes, are larger groups of nerve cells located within a common membrane and forming a community of labour.

The cells of the metabolic centres in the brain as well as those of the ganglia in the trunk send out two kinds of nerve currents: a driving current and a braking current. The cells that emit the driving current are called sympathetic cells, while those which produce the braking current are called parasympathetic or vagus cells. These latter received their name because the old anatomists found a thick nerve bundle which they were unable to trace to any specific destination and therefore named it " vagus," or vagabond. The inter-relations of the sympathetic and the vagus are very complex and have not yet been entirely elucidated. The sympathetic elicits all those reactions that aid the work of the body. It accelerates cardiac activity, contracts the dermal vessels, and dilates the bronchi so that more oxygen enters the blood; it mobilizes the sugar from the liver, so that the muscles will receive materials to carry on their function, etc. The action of the vagus is opposed to that of the sympathetic. It stimulates intestinal activity so that the individual may feed during the period of recuperation; it stimulates the kidneys in order to remove the wastes of the body. It slows down respiration, cardiac activity, and the circulation so that the body may recuperate.

Vagus and Sympathetic Substances. Like all the organs the hormonal glands are also included within the

network of the sympathetic system and their secretions depend upon whether they are stimulated by the vagus or the sympathetic. If the adrenal is stimulated by the sympathetic, its medulla secretes adrenalin, which produces sympathetic effects. If, however, the adrenal is stimulated by the vagus, the cortex of the gland secretes choline, a substance producing diametrically opposed effects. The nerve currents act on all the other organs of the body just as they do on the hormonal glands. When the brain sends an action current to a muscle fibre, a substance called acetylcholine forms at the point of contact between the nerve and the muscle. This substance initiates the process of coagulation, which is the cause of muscular contraction. Acetylcholine appears for only a fraction of a second; then it is destroyed by a ferment. The entire process occurs with approximately the same speed as the vaporization, compression, explosion, and expulsion of the gas mixture in a motor-car engine. In some individuals the ferment is apparently too powerful and destroys the acetylcholine so rapidly that no muscle contraction takes place. Such a person is unable to contract his muscles. Until the discovery and elucidation of the process described above, the essential nature of myasthenia gravis, as this disease is called, was unknown, and the condition was considered hopeless. After it had been discovered that muscular contraction was an enzymatic process, it then became possible to look for a substance which would act as an

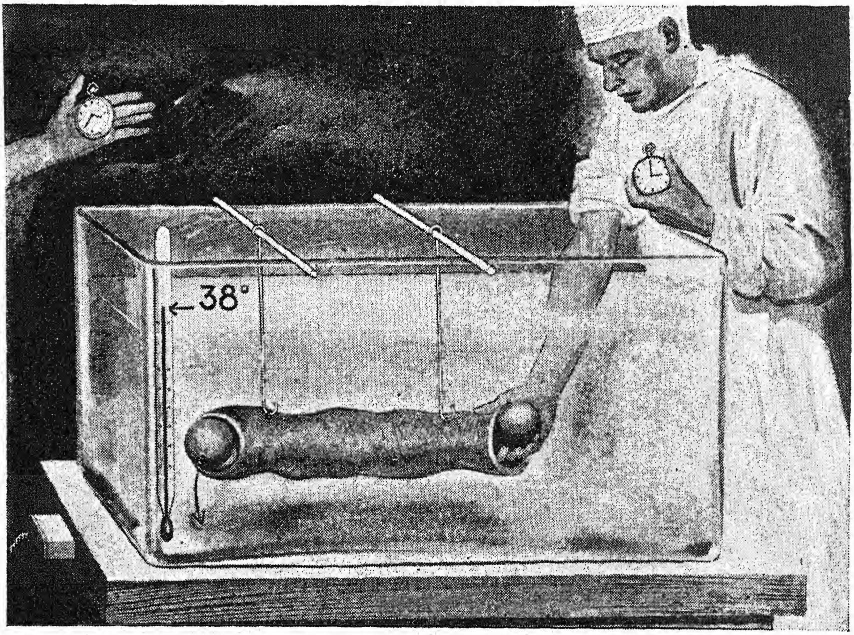


FIG. 270. *The activity of the intestine, like that of the heart (Page 148 and Fig. 120) can be maintained for hours after death, because it has its own nervous system. A rubber ball inserted into a length of intestine is carried through it and later expelled.*

anti-ferment and weaken the excessive action of the ferment. Such a substance was actually discovered in the form of physostigmin. If a patient suffering with myasthenia gravis is injected with this substance, he can move his muscles as long as the drug is effective.

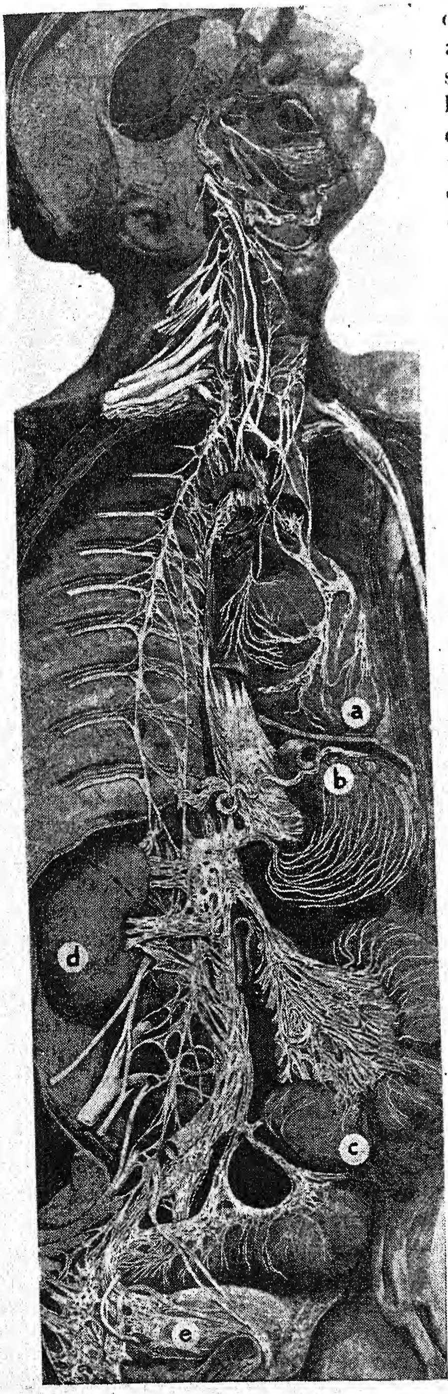
Sensation and the Sympathetic. Man senses or feels with the cells of the cerebral cortex and perceives only those stimuli which present themselves to these cells. We remain unconscious of, or perceive only dully, anything that occurs in the domain of the sympathetic nervous system. The organs supplied by the sympathetic lack sensation. The intestine can be cut, yet the individual affected will not feel it. When Greek mythology relates that Prometheus was punished for stealing the fire of the gods by the eagle of Zeus devouring his liver daily, causing him to suffer dreadful pain, the legend incorporates a medical error. Prometheus could have experienced no more pain when the eagle devoured his liver than a tuberculous patient does when the tubercle bacilli make holes in his lungs, giving them the appearance of a Swiss cheese. In the sympathetic system there are no definite feelings such as pain, but only dull, undefined sensations such as the feeling one experiences when riding up or down in an elevator, the gnawing sense of hunger, or the feeling of paralysis induced by fear.

Operating Without Pain

In operations on man for resection of the intestine, the cutting and repair of the intestine may be carried out without any anæsthetic and without causing pain to the patient if the abdomen has been opened under local or general anæsthesia. However, impulses which may reach consciousness and produce a sensation of pain can arise in the afferent nerves of the viscera in consequence of particular types of stimulation, such as distension or compression, most frequently in connection with pathological processes. Such pains are not localized in the viscera, but are referred to certain parts of the skin. This fact is utilized in diagnosing the nature and site of visceral disease.

Controlling the Sympathetic

Just as the pain sensations of the viscera are not brought directly to the consciousness of the individual because there are no connecting nerve paths, so, conversely, volitional impulses cannot descend from the cerebrum to the organs in the domain of the sympathetic system. We are unable to give orders to our viscera, and it is a moot question whether the intestine belongs to us or whether we are not rather subject to our intestine. Be that as it may, it is nevertheless true that the nervous system, like other organs of the body, is subject to the law of training. Training develops the cells and conduction tracts of the nervous system. If such exercises are begun early enough, the volitional centres of the cerebral cortex can attain a certain degree of control over the fibres of the sympathetic system. Upon this fact are based the so-called miracles of Oriental fakirs, such as the voluntary alteration of the heart rate mentioned above (pages 152-153). The fakir can quicken or retard his pulse; he can slow down his respiration and his metabolic processes to such an extent that he can be buried for ten days with-



out being suffocated. Such abilities are occasionally discovered as curiosities in every large group of human beings. One finds individuals who can innervate their pupils at will, or who can sweat at a command; indeed, there are individuals who can even control very limited portions of the body, who are able to perspire only on the left forearm, or to blush only on the right side of the chest.

Hypnosis. The hypnotic state is a sleeplike condition of the nervous system, as yet unexplained, in which it is possible to inhibit or to stimulate at will not only individual nerve paths of the cerebrum but also those of the sympathetic system. If a pencil be pressed against the hand of a good subject during the hypnotic state, while at the same time he is told that it is a red-hot rod, the skin at the point of contact will become red under the influence of the unnaturally strong power of imagination and volition, just as if the pencil were actually a red-hot rod. Indeed, even blisters may arise. On the other hand, the sensation of pain may be inhibited to such an extent that a needle may be drawn through the subject's body without the slightest pain being felt. Similarly, the tonus of the musculature may be increased to such a degree that the body becomes as rigid as a board and can be laid on the top of two chairbacks for hours without collapsing.

FIG. 271. *The sympathetic nervous system combines with the vagus (Fig. 261) to form a vast, complicated network of neurons, extending from the brain to all parts of the body. Here, along the spine, can be seen the sympathetic ganglia. Also visible are the large plexuses of the heart (a), stomach (b), intestine (c), kidney (d) and bladder (e)*

CHAPTER XXXV

The Central Nervous System

THE SEGMENTAL ARRANGEMENT. THE REFLEX ARC. THE CELL TYPES OF THE SPINAL CORD. INFANTILE PARALYSIS. TETANUS. PAIN. THE BRAIN STEM. INSTINCTS. HEADACHE. HYDROCEPHALUS. THE CORTICAL AREAS. INHIBITORY FIBRES. APOPLEXY. THE SENSORY SPHERE. VISION. MEMORY DEAFNESS. THE ASSOCIATION FIBRES. THE WEIGHT OF THE BRAIN. SLEEPY SICKNESS. ANÆSTHESIA.

THE sympathetic nervous system is the sum total of all the nerve cells and their fibres (neurons) that supply the viscera. The neurons that control the sensory organs of the skin and the skeletal muscles have collected along the midline of the back between the skin and the skeleton as shown in Figure 23 (b) and are protected by the backbone (c). Here they form a long cord, the spinal cord, of which the anterior end has enlarged to form the brain [Fig. 21]. In contrast to the sympathetic system the brain and spinal cord are called the "central nervous system."

The Segmental Arrangement of the Central Nervous System. In the earlier stages of its embryological development the human body possesses a segmental structure [Figs. 23, 25]. Corresponding to these segments the central nervous system during its early developmental stages is nothing but a series of nerve nodes, ganglia, arranged one behind another [Fig. 272]. Three of the uppermost ganglia grow together to form the triplet nerve, the trigeminus, of which the upper branch supplies the eye, the middle branch the upper jaw, and the lower branch the lower jaw (Tr). The lower ganglia grow together, forming a continuous rod which is ingeniously suspended in the bony canal of the vertebral column and is called the spinal cord [Fig. 33]. The segmental structure

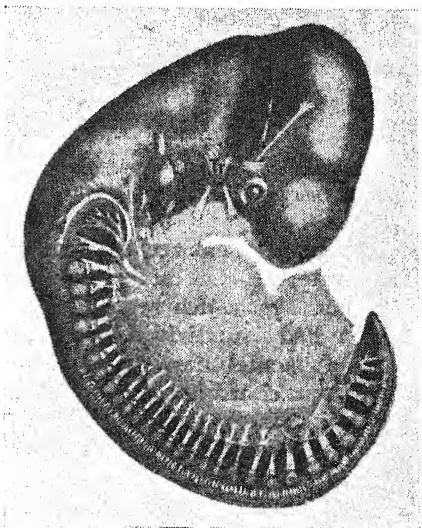


FIG. 272. *A human embryo at the age of four weeks (natural size: $\frac{2}{5}$ inch), showing how the nervous system is constructed in segments. At this stage of development, the nervous system consists of approximately forty nerve nodes, or ganglia, which later grow together to form the brain and the spinal cord.*

of the spinal cord is still discernible externally. Thus the sensory cells have not grown together with all the other cells to form the spinal cord, and have remained suspended like a string of pearls outside the spinal cord in the form of individual ganglia [Fig. 33 (Ggl)]. Besides, the peripheral nerves that leave the spinal cord are distributed over the body along sharply defined segments. If the skin areas supplied by the glia, red vesicles appear on the skin, being limited with mathematical precision to those areas supplied by the affected segments [Fig. 274].

Grey and White Substances. If one cuts through the spinal cord, the cross-section presents the picture shown in Figure 275: a grey butterfly figure on a white ground. In the grey substance lie the nerve cells, while the nerve fibres that arise from them traverse the white substance.

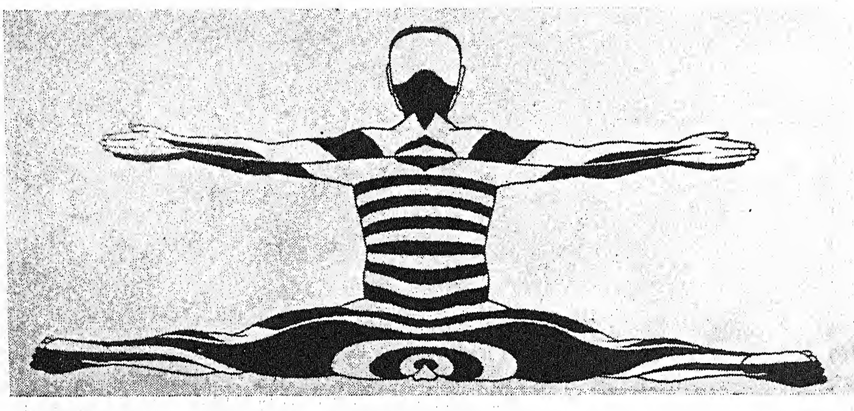


FIG. 273. *This is not the variegated costume of a circus clown, but a diagram showing how the nerves from the segments of the spinal cord are distributed over the skin.*

individual segments are demarcated, one obtains the comical figure shown in Figure 273, which represents the human body subdivided according to its segmental nerve supply and not a circus clown in tights, as might be imagined at first sight.

Shingles (Herpes Zoster). A knowledge of this segmental distribution is of the greatest importance for the recognition of nervous diseases, since the distribution of the lesions permits one to deduce the location of the disease focus in the spinal cord. A typical segmental disease is the condition known as shingles, in which, as a result of a comparatively harmless disease of the spinal gan-

The Reflex Arc. The spinal cord is essentially a reflex apparatus composed of a number of "segmental" reflex arcs that are arranged one behind another. The external stimuli (a) coming from the skin are received by the sensory cells in the ganglia (b) near the spinal cord and transmitted by means of a brush contact (c) to the motor cell of the spinal cord (d). In response to the stimulus, the cell sends an action current (e) to the muscles or glands. Since the stimulus in its passage thus describes an arc, the path (a-e) is called a reflex arc.

The Patellar Reflex. In order to demonstrate a spinal reflex, cross

your legs like the man in Figure 276, allowing the crossed leg to hang loosely as if it did not belong to the body. Now strike the patellar ligament, situated directly below the patella, with the edge of the hand or a small hammer. The stimulus passes from (1) by way of sensory cell (2) into the spinal cord, where it is transferred to a motor cell (3), which now sends an action current (4) to the leg muscles, causing the leg to twitch, as if one wanted to kick an enemy in defence. This is actually its purpose, since a reflex is essentially an appropriate, *automatic* response to an external stimulus. The "mental" life of lower animals with "spinal-cord souls" is hardly more than a series of reflex responses to the stimuli of the environment.

Ringing a Bell

The process behind the patellar reflex is precisely analogous to that which occurs when we ring the bell (1) of a closed door, sending a sensory stimulus (2) into the interior of the house, whereupon the doorman answers the buzzer stimulus by pressing on the motor cell of the door-opener (3) and causing the door (4) to open.

The Cell Types of the Spinal Cord. The spinal cord consists basically of a large number of such reflex arcs. Figure 277 illustrates its basic structure pattern, which is common to all vertebrates. The sensory neuron passes upwards from the skin (S) as a fine line. Each segment has one neuron. Near the small sensory cells lie the larger motor cells, from which the motor fibres pass as heavy lines to the longitudinal muscles (L Mu) and the circular muscles (C Mu). The pear-shaped internuncial cells (IC) connect the neurons of the various segments with one another. The same general pattern is present in the human spinal cord, only there it is much more complicated.

The Tracts of the Spinal Cord. In Figure 277 the sensory fibres, the fine lines (se), and the motor fibres, the heavy lines (mo), are drawn separately. In all higher organisms, however, they run together in common cables (like the wires in electrical apparatus). The human nerves are "mixed nerves." In them the sensory fibres pass upwards from the skin to the brain, and at the same time the motor fibres run downwards from the brain to the muscles. They also contain the tonus fibres of the muscles, the vasomotor nerves for the vascular walls, sympathetic and vagus fibres—all united within a

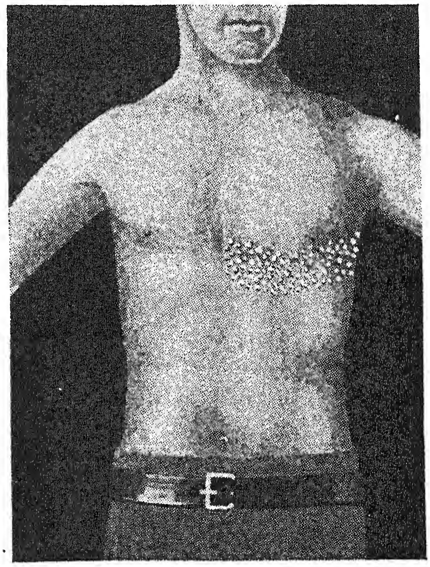


FIG. 274. *Shingles is a disease affecting definite segments of the spinal cord. A rash appears upon the skin, limited precisely to the area supplied by the diseased nerves.*

common cable, the nerve. Both at its origin and at its end a nerve breaks up into individual fibres like the electrical cable. After arriving in a particular area of the body the various fibres separate, the motor fibres going to the muscles, the vasomotor fibres to the vessels, and the "secretory" fibres to the glands in order to activate them to secrete.

Nerve Pattern of the Spine

Similarly the cable breaks up in the spinal cord. The motor fibres that leave the different nerves unite to form a uniform motor cable, just as do the sensory fibres, the tonus fibres, etc. These cables run upwards and downwards through the white matter of the spinal cord in the form of tracts arranged in a definite pattern. Figure 278 shows some of the principal tracts of the spinal cord in cross-section, and in Figure 279 they may be seen in full length. In both pictures the motor tracts that transmit the volitional impulses of the brain to the muscles are drawn in black; the sensory tracts which conduct the sensations of the body to the brain are light.

The Motor Tracts. There are two motor tracts, called the pyramidal tracts because they pass through a part of the brain called the pyramid.

Voluntary Movements

Since it runs in the anterior part of the spinal cord, tract (1) is called the anterior pyramidal tract. Historically it is the oldest and most important tract of the spinal cord, since through it the organism sends a volitional impulse from the brain to the muscles, producing movement. It is the action tract. Place this book in front of you and support your head with your left hand so that it covers your left ear, meanwhile turning the pages with your right hand. In the area of the skull covered by the left hand lies the motor centre for voluntary movement of the right arm. At this moment an action current has passed from this centre downwards through the pyramidal tract to the shoulder. Having arrived here the current passes over to the right side of the spinal cord and ends in the terminal filaments of the first neuron. These filaments transmit the stimulatory current to a motor cell in the anterior horn of the right side of the spinal cord. This cell, as the second neuron, then carries the current to the muscles of the right hand. In Figure 279 the player is kicking a soccer ball. In this case the current has travelled down to the lowest of the five plates shown within the spinal cord, whence it is carried to the muscles of the thigh.

Strong and Weak Currents

Besides this anterior tract there is another pyramidal tract, likewise consisting of two neurons, tract (2), which takes a different course. The two lateral pyramidal tracts cross at the level of the neck—this is the well-known crossing of the pyramidal tracts, shown in Figure 293. Tract (1) sends an ignition current to a muscle. After the muscle has been activated by the ignition current of the anterior pyramidal tract it is maintained in tension or motion by the weaker current of the lateral pyramidal tract. By means of the strong current of the anterior tract we kick a football or push on the pedals of a bicycle; by means of the weak current of the lateral pyramidal tract we control a pen while writing or a bow in playing a

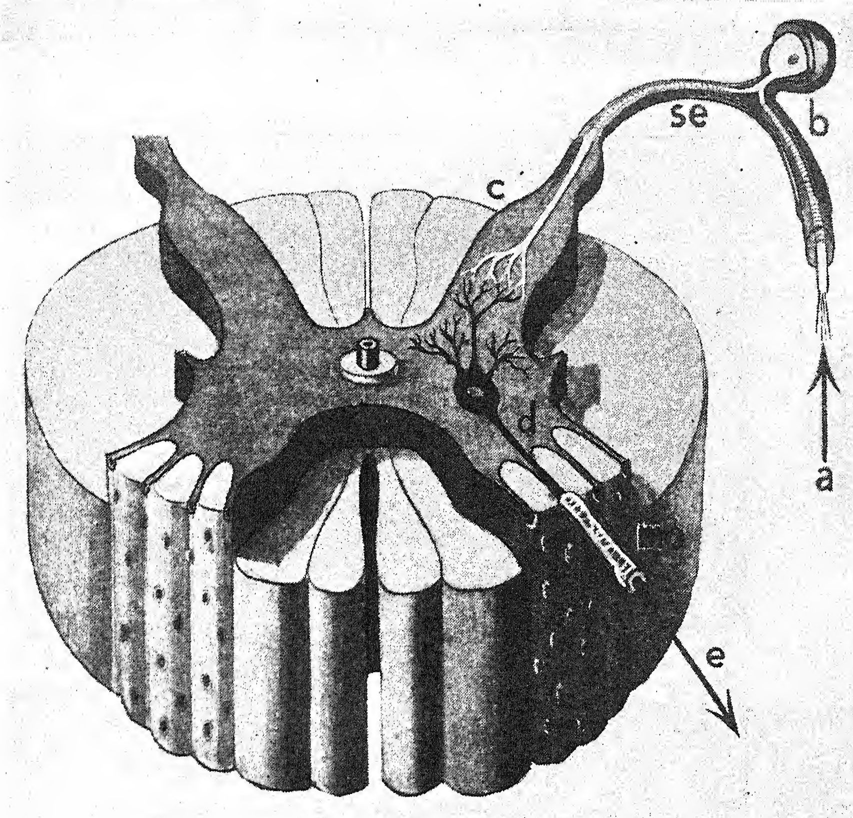


FIG. 275. *A cross-section of the spinal cord, showing the grey "butterfly" structure in which the nerve cells are located. The path from (a) to (e) through the cells is a "reflex arc," or passage traced by a nerve stimulus (Page 398).*

violin or other stringed instrument.

Infantile Paralysis. Infantile paralysis is an infectious disease which occurs epidemically, affecting predominantly children and young people, although adults may also be affected. It consists essentially in an inflammation of the motor cells of the anterior horn. If these cells are destroyed, the volitional tract from the brain to the muscles is interrupted and the corresponding muscles are paralysed. Man has about 800,000 anterior-horn cells. If only a few hundred die, the affected individual can bear the loss, and notices it only as a certain weakness that can be overcome by training and the use of adjacent muscles. If all the cells of entire segments die, however, complete paralysis is the result. If the cells that activate the diaphragm are affected, it becomes immobile and the individual dies of respiratory paralysis. To prevent this unfortunate eventuality the "artificial lung" has been constructed. This is an apparatus which moves the thorax by alternately lowering and increasing the pressure

within the metal chamber, thus creating a rhythmic motion of the thoracic wall analogous to the respiratory movements [Fig. 282 (2)]. In some cases, instead of placing the individual in the artificial lung, the respiratory muscles can be stimulated by electrical currents that are substituted for the ignition current of the dead anterior-horn cells.

Tetanus. Two other disorders of the motor, anterior-horn cells are tetanus and strychnine poisoning. Tetanus is caused by a bacillus, which lives in street dirt, dung, and garden earth, and which proliferates in wounds contaminated by these materials. The toxin, which is produced by the bacillus and passes from the wound into the blood-stream, is one of the strongest poisons. An entire city can be poisoned with a teaspoonful of tetanus toxin. It irritates the anterior-horn cells, producing extremely painful sustained muscular contractions, which in turn flood the body with fatigue substances to such a degree that in severe cases death results from exhaustion. Tetanus toxin is one of the bacterial poisons against which it has been possible

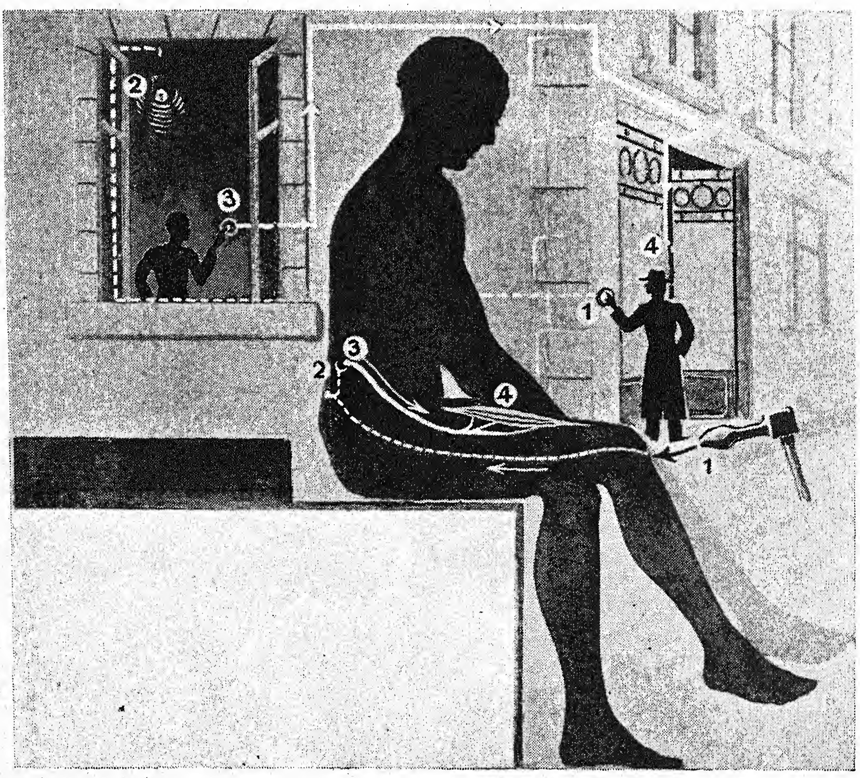


FIG. 276. *A reflex path functions like an automatic door-opener. In response to the pressure stimulus (1) on the bell button outside the body (in this case, the patellar ligament), the bell of the sensory cell (2) rings in the spinal cord. The motor cell (3) responds with an action current (4) causing the leg muscles to contract sharply.*

to prepare an effective anti-toxin. Anyone who sustains a wound contaminated with street dirt should receive an injection of tetanus antitoxin as soon as possible, preferably on the same day, as a protection against the danger of any infection with tetanus bacilli.

Strychnine Poisoning. Strychnine poisoning is very similar to tetanus, in that the anterior-horn cells are also irritated, producing horrible twitchings and tetanic convulsions that end fatally within a few minutes. Taken in small doses strychnine is a stimulant and is therefore contained in almost all tonics.

The Sensory Tracts. The sensory tracts that conduct external stimuli upwards through the spinal cord to the brain are drawn in white in Figures 278 and 279. At the outer edge of the spinal cord the lateral cerebellar tract (3) runs to the equilibrium apparatus of the cerebellum. More medially, in tract (4) lie the nerves that inform us of pain and temperature sensations. Posteriorly lie the tracts that transmit touch impressions (5) and the muscle sense arising from muscular tension (6). In Figure 279 the sensory tracts are also characterized by the circumstance that the cells of the first lower neuron lie outside the spinal cord as ganglia.

Maintaining Equilibrium

Having become well acquainted with these six spinal tracts, we are now in a position to understand more fully the portrayal of the soccer player. By means of the anterior pyramidal tract (1), he sets his right foot in motion to kick the ball. The touch tract (5) enables him to feel that he has hit the ball. In order not to fall over backwards in consequence of the upward motion of his leg, the player tenses his raised arm as a counterpoise. For this purpose he sends a tension current to the muscles of his arms through the lateral pyramidal tract (2). He controls the position of his body, which is balanced on the left foot, through the equilibrium tract, which passes to the cerebellum (3). The player feels the warmth of the sunshine through the temperature tract (4).

Loss of Muscle Sense

Tabes. Tabes is a syphilitic disease of the spinal cord which appears ten to twenty-five years after the primary infection in approximately three per cent of uncured cases. The muscle sense, as well as the consequences of a break in the corresponding tract of the spinal cord and the treatment of the resulting condition by means of exercises, have been described in Chapter VIII. In tabes the fibres of tract (6), which inform us of the degree of muscular tension, disappear. Usually the fibres vanish in the lumbar region of the spinal cord so that the upper half of the individual's body remains healthy, while in the lower half he loses his muscle sense and with it the ability to stand and walk [Fig. 282 (3)].

Pain. Pain is not, as some believe, an enemy of human happiness, but rather its protector. It informs an individual when his body is being injured. When it becomes cold outside, it shouts: "Go back and fetch your gloves, so that your fingers won't freeze." When the wall of a tooth becomes thin, it sends urgent telegrams to the brain: "To the dentist!" When a nail penetrates the sole of a shoe the foot cries out at every step: "Pressure . . . pres-

sure . . . pressure. If you don't relieve me of this pressure, I shall be chafed and a wound will be created so that you won't be able to walk upon me." The importance of pain as a protector of life is vividly demonstrated by diseases in which the patient loses his pain sense.

Syringomyelia. This is a disease characterized by the occurrence of flute-like cavities extending for a variable distance in the pain and temperature tracts at the level of the neck. The pain and temperature fibres connecting hand and brain are interrupted. An individual boasts at the table that the teapot isn't so hot. Why, he can touch it without burning himself. And he imagines himself a hero—actually he is the victim of a disease situated in his neck. Generally the patient comes to the physician with wounds on his fingers. "I must have struck my finger while hammering in some nails last week. It didn't even hurt, but the wound does not heal." It does not heal because the patient does not take care of it, since his sensitivity for pain is decreased. Or he comes to the doctor with the typical story: "I became so absorbed in reading that I forgot everything. Suddenly I smelled something burning and when I looked up I saw that my cigarette had burned down and singed the skin of my finger." This does not happen to a healthy person, since a normal individual feels when the heat of a burning cigarette comes close to his finger and extinguishes the cigarette. This man, however, did not feel it because the pain and temperature tracts in the cervical region of his spinal cord had become cracked [Fig. 282 (1)].

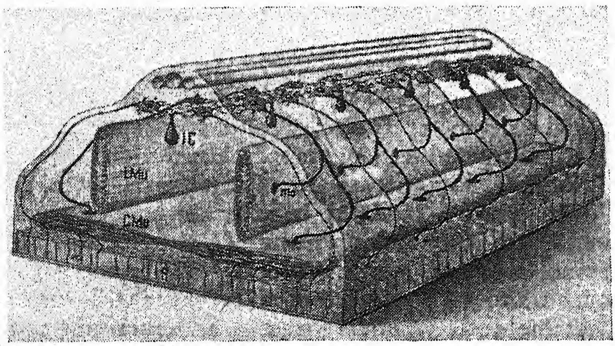


FIG. 277. *Schematic diagram of the spinal cord. Passing upward from the skin (S) are the sensory neurons (se). The heavy lines (mo) represent the motor fibres. The internuncial cells (IC) link up the different neurons. This basic structural pattern is common to all vertebrates.*

Leprosy. The frightful mutilations of leprosy, where fingers, toes, nose, or ears may be lost, are due to a loss of pain sensation in the course of the disease. The leper burns his hands, or lets them freeze, or he may lie for hours on his arm so that the circulation is disturbed and the arm dies. Pain is harsh, merciless, and often senseless, because the body functions automatically by means of reflexes and is only adjusted to normal conditions.

The Rhomboid Fossa and the "Vital Node." Where the spinal cord passes over into the brain, it widens out, forming the medulla oblongata [Figs. 280 (a), and 281 (f)], which encloses a lozenge-shaped depression, the rhomboid fossa [Fig. 280 (b)]. In this depression lie the

frequently mentioned metabolic centres, whose injury causes immediate death. In addition to these metabolic centres the medulla oblongata also contains an entire series of centres in which the stimuli that have been conducted thither by the spinal tracts are collected and arranged in the form of "stimulus images" for transmission to higher nerve centres. This arrangement of individual stimuli to form "stimulus images" is a general and important process in the nervous system. Consider this page. It is composed of individual letters, each of which was put in its place by pressure on the keys of a machine resembling a typewriter. The pressure on the keys was exerted at definite times and in accordance with a certain pattern, producing as a final result an entire page. Together with others this page was then printed by a printing press.

Comparison with Television

In reading these sentences and looking at this page, a very similar process takes place in our nervous system. The individual stimuli received by the sensory organs are collected and arranged in the form of a stimulus image in certain centres of the medulla oblongata, which is then sent to the higher centres of consciousness. This comparison with the work performed by the compositor is easily comprehensible, but one probably comes closer to a true understanding of the processes in the nervous system if television and the processes underlying it are used for comparison. In television a large number of individual dots of a picture are transmitted in extremely rapid serial succession in the form of individual electrical stimuli, and are then reconstituted into a picture on a disk consisting of dots. The passage of nerve stimuli in the form of current impulses through the spinal cord and their reconstitution to stimulus images in the medulla oblongata must be conceived of as being quite similar. In daily life we hardly ever work with individual stimuli, but almost always with such composite stimulus images. Close your eyes and touch the paper of this page with the tip of your finger. We cannot do very much with this single stimulus. If we did not know that we were touching a book, we could not derive this knowledge from this single stimulus. Now let

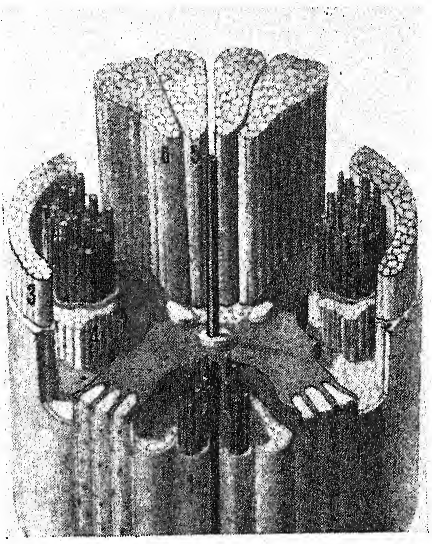


FIG. 278. *The tracts of the spinal cord which are grouped around the "butterfly" figure (Fig. 275). They comprise motor and sensory tracts. The motor tracts (dark) are: (1) anterior pyramidal tract, which conveys contraction currents; (2) lateral pyramidal tract, which conducts tonus impulses. The sensory tracts (light) are: (3) lateral cerebellar tract, conducting impulses for maintaining equilibrium; (4) temperature and pain tracts; (5) tract for touch; (6) tract for the muscle sense.*

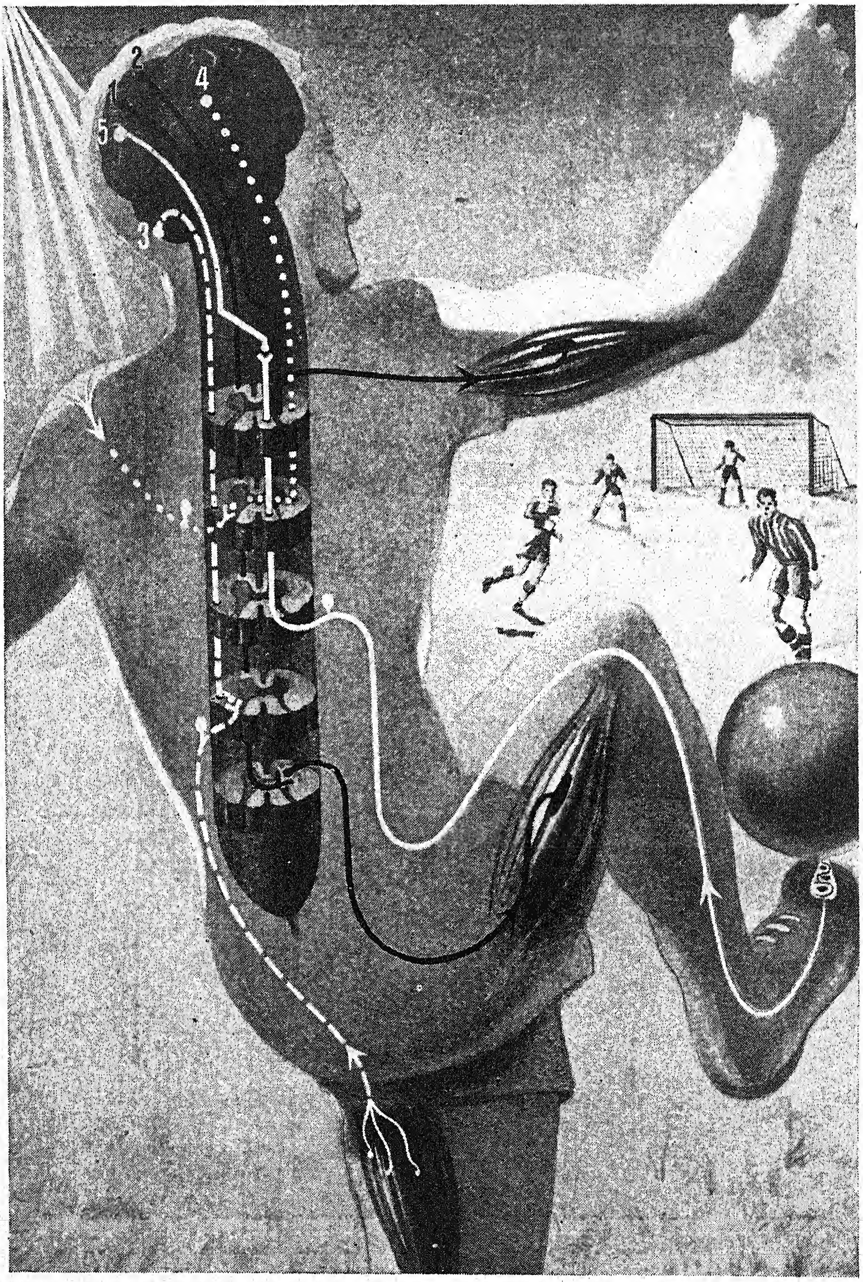


FIG. 279. *Here the course and functions of the five most important tracts of the spinal cord are traced in the body of a football player. The numbers correspond to those in Figure 278, with which this illustration should be compared. See also Page 403.*

us take the entire book in both hands. Immediately we conclude: "This is a book." We have received a large number of stimuli; we feel its thickness, format, weight, that it consists of covers and pages, and from all these stimuli we form a stimulus image that we send in its totality to the cerebral cortex, which concludes: "This is a book."

The Olive, Deiters's Nucleus, and the Reticular Substance. The structure labelled (Ol) in Figure 280 is known as the "olive" or olivary body. It collects the stimuli of the body in walking and standing and thus makes it possible for us to walk and to stand. A neighbouring apparatus, Deiters's nucleus, controls the relations between head posture and eye position. A seeing individual is like a camera walking through the world on its tripod and taking pictures. In order that the pictures be properly focused the eyes must continually be automatically adjusted to any changes in the position of the head.

Complex Actions

This continually varying adjustment is made by the static apparatus of Deiters's nucleus. Near it lies the "reticular substance." This is a switch which shifts olfactory and gustatory stimuli arising from food over to the muscles engaged in swallowing. Like standing and walking, swallowing is a very complex collective action of a number of muscle groups. The chief control is exercised by this reticular substance. If it is destroyed, the individual can no longer swallow. The medulla oblongata contains dozens of such mechanisms, perhaps more than a hundred. In its totality the medulla is about as large and as heavy as a boiled egg after the shell is removed. It can easily be held in the palm of the hand. Yet there is nothing on earth equal in size and weight to this piece of nerve substance, which is located between the spinal cord and the rest of the brain, that incorporates within it so many highly complex pieces of technical mechanism.

Observatory of the Body

The Cerebellum. The largest equilibrium switch between the spinal cord and the brain is the cerebellum. It is as large as an orange and is attached to the inferior surface of the cerebrum [Fig. 281 (g)].

In order to obtain a picture of the remarkable structure of the cerebellum, take an orange or a tangerine and remove the skin. Just as an orange is composed of sickle-shaped sections, so the mass of the cerebellum is arranged in "leaves," and like the sections of an orange each leaf is at a slight angle to its neighbour [Fig. 281 (g)]. If one cuts through the cerebellum, the sectioned surface presents the leaf-shaped appearance shown in Figure 287 (f). The cerebellum is an apparatus for spatial orientation; it is the astronomical observatory of the human body. To obtain some idea of the arrangement of the astronomical instruments in the cerebellum, take several slices of bread and some small radishes and make a model like the one shown in Figure 283. The bread slices are the cerebellar leaves; the knitting-needles are the fibres that connect the apparatuses of the leaves.

When this basic plan is understood, one can then go on to study the natural relations as represented in Figures 284 and 285. The numbers in the two pictures corres-

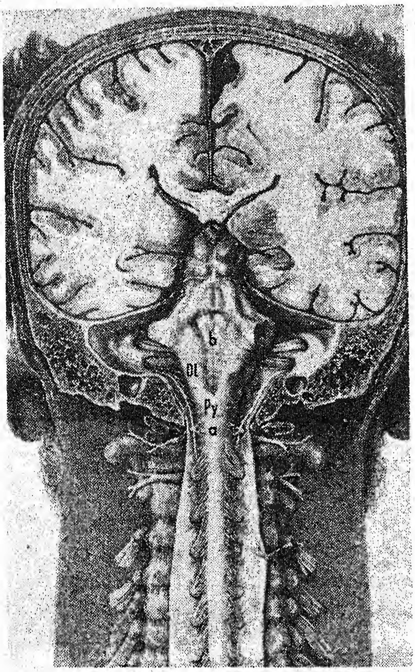


FIG. 280. *The central station of the nervous system: the medulla oblongata, where the tracts of the spinal cord terminate and transmit their impulses to other tracts, and where the vital centres for respiration, blood-pressure, muscle tension, etc., are situated. Death occurs inevitably if these vital centres are destroyed.*

pond. Figure 284 is a diagram, Figure 285 is a simplified picture of the microscopic structure of the cerebellum. First let us study the diagram. The cerebellum is not the sensory organ of equilibrium, but the organ for the regulation of equilibrium. The cells for the perception of our position in space are in the inner ear. Close your eyes and move your head about; at any moment you are aware of the position of your head. We owe this perception to the organ of equilibrium (1). Through connection (2) this organ sends reports to the cerebellum regarding the position of the head. These reports are transmitted to the large Purkinje cells (P)—so called after the Czech scientist Purkinje, who discovered them—through connection (3). Secondly, through the muscles that communicate their state of tension to the cerebellum, the Purkinje cells receive information regarding the position of the trunk and the limbs. Out of the totality of these stimuli a stimulus image is composed which gives the cerebellum a conception of the spatial position of the various parts of the body.

The Cerebellum at Work

These sensations of tension from the muscles are first perceived by means of the spindles. They then pass from the muscles (4) by way of the sensory nerves (5) upwards through the lateral cerebellar tract. Then the impulses travel over connection (7) to the T-cells (8), so called because their fibres (9) ramify in a T-shaped pattern so as to communicate simultaneously with the Purkinje cells of several leaves. The internuncial cells (10) connect all the Purkinje cells of each leaf so that they form a unit. Between the Purkinje cells lie the large Golgi cells (11), whose function is unknown. After the cerebellum has registered the received stimuli and derived a picture of the position of the head and limbs from them, it responds to the stimuli with appropriate reaction currents and movements. From the Purkinje cells an impulse passes downwards through connection (12) to the dentate nucleus (13) in the medulla oblongata, where it is shunted to the lateral pyramidal tract (14). The impulse then travels through this tract down the spinal

cord and through the motor nerves (15) to the muscles (16).

The structure and the function of the cerebellum have intentionally been presented in somewhat great detail, so that by means of this example one may obtain an idea of the manner in which such a nervous switch is constructed and functions. All parts of the brain work like the cerebellum, but, of course, with corresponding modifications; and if one wanted to describe all of them in equal detail, the information would certainly fill a volume of an encyclopædia. To be sure, what has been

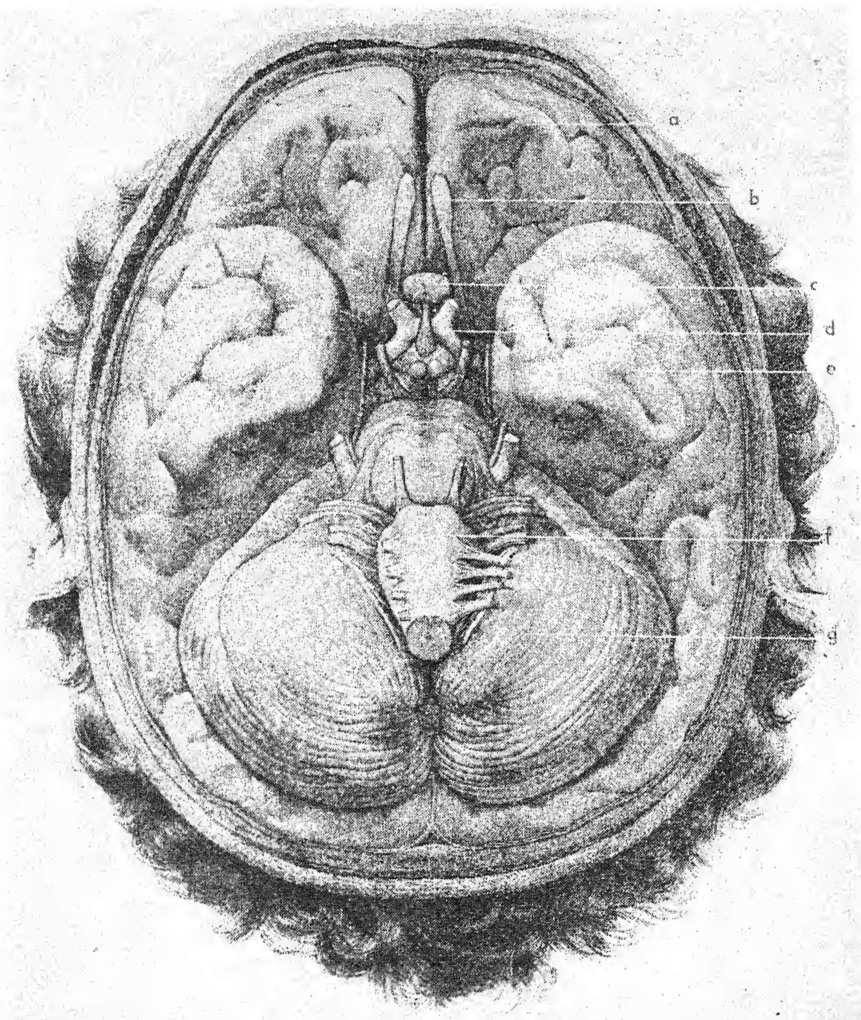


FIG. 281. *The human brain as it appears from below. Its component parts, with widely different functions, are: (a) frontal lobe; (b) olfactory lobe; (c) pituitary chiasma; (d) optic chiasma; (e) temporal lobe; (f) medulla oblongata; (g) cerebellum.*

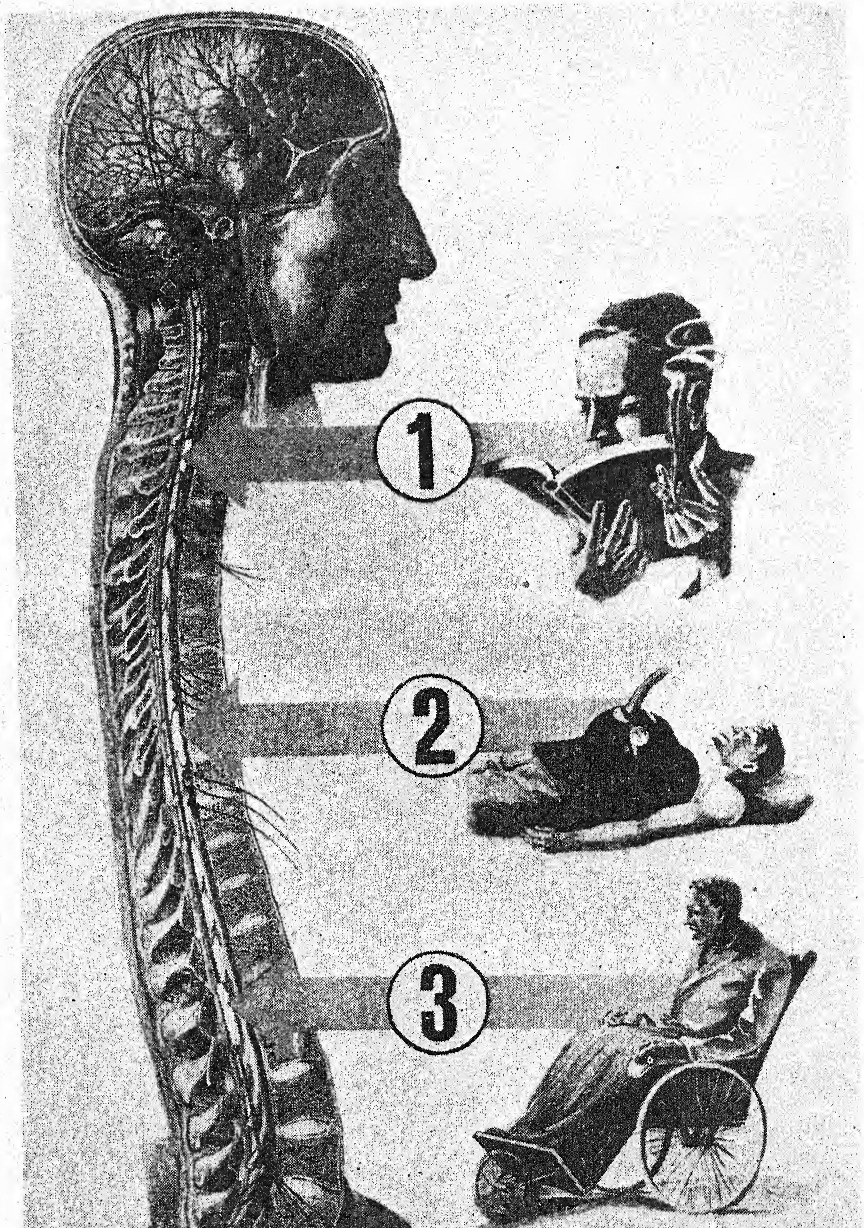


FIG. 282. *Three serious diseases of the spinal cord. (1) Syringomyelia, a sufferer from which may unconsciously burn and injure his fingers because the pain and temperature tracts have been destroyed. (2) Infantile paralysis, which paralyses the diaphragm. (3) Tabes dorsalis; the nerve tracts for muscle tension in the legs degenerate.*

described here is only a sketchy approximation to the truth, for what we see spread out over a page in Figure 285 is compressed within the space occupied by a farina granule, and where one connection is drawn in the picture, there are actually seventy-five.

Loss of the Cerebellum

In each animal the development of the cerebellum corresponds to the mode of locomotion of the animal. The sluggish carp has a small cerebellum, the mobile salmon a large one. A sheep has a small cerebellum, while the horse, which is tall and maintains its balance in a manner as skilful as it is elegant, has a splendidly developed cerebellum [see Fig. 309].

Diseases of the Cerebellum. If a dog is deprived of half its cerebellum, it loses the ability to walk in a straight line. If a bowl of food is placed at a distance of about three feet from the dog, it runs towards it but passes by it laterally like a comet near the sun. Now if the dog is deprived of the remaining half of the cerebellum, one might expect that the dog would be totally unable to walk. This is not so, however. After the removal of the second half of the cerebellum the dog walks normally again. The same is true of man. In diseases affecting only part of the cerebellum, the affected individual loses his equilibrium, suffers from cerebellar vertigo, and assumes compulsive attitudes. However, if a person is born without a cerebellum, he exhibits no peculiarities. Indeed, the condition is first discovered after death.

The Extra-Pyramidal System. The astounding fact that such a large and marvellously constructed part of the brain as the cerebellum can be completely eliminated without causing any perceptible disturbance of the organism is explained by the equally astounding circumstance that the human nervous system is in the midst of moving. Owing to the adoption of an erect position by the body and the liberation of the arms for work, the jaws were relieved of a heavy burden and became smaller. As a result, space became available in the skull, so to speak, for expansion. The brain then opened new departments and is today in the midst of these alterations. The cerebellum is moving to the front, and near it, situated in the brain stem, just in front of the cerebellum, there is already a new telephone exchange. When the cerebellum is out of order and unable to function, the individual employs the new telephone exchange. This new department is called the extra-pyramidal system because it is situated extra-pyramidally and does not employ the classic pyramidal tract for its connections. Figure 287 shows the human brain in cross-section. Posteriorly at (f) we see the oak-leaf pattern of the sectioned cerebellum; in front of it is the brain stem, shaped like the knob of a walking-stick.

Personal Traits

Within this structure the extra-pyramidal system, shown by dark lines, has developed as a complicated network of neurons and switches which regulates the finer and more delicate movements, tensions, and actions of the muscles. Everyone moves about, but each individual exhibits some personal characteristic in his movements. Every painter has his characteristic "stroke"; similarly every violinist,

orator, and dancer presents some individual peculiarity. Historically the extra-pyramidal system is a recent acquisition and develops relatively late, not until after the age of three. For this reason children do not learn to dance, sing, write, or paint sooner. It likewise degenerates and grows old quite early.

Paralysis agitans—a constant tremor and shaking of the hands or the head combined with a mask-like appearance of the face—is an affection of the extra-pyramidal system in later life.

The Brain Stem. The brain stem is composed of a number of large ganglia. The brain stem is the ancient brain of animal history, the brain of the lower vertebrates. A carp has only a brain stem without any cerebrum covering it [Fig. 287]. The ganglia of the brain stem are the seat of the two primitive mental functions that comprise the psyche of the lower animals—perception and instinctive action.

Primary Perception. The neurons of the sensory organs end in the ganglia of the brain stem. Both the optic nerve [Fig. 296 (I)] and the acoustic nerve [Fig. 298 (3)] terminate here, as well as all the tracts that pass upwards through the spinal cord from the sensory organs of the skin [Figs. 266, 279, 294]. By means of the cells situated here, living creatures perceive the world, but without recognizing it—that is, without remembering it, or continuing to think and feel about it. When we see a rose, we immediately begin to think about it. We recall that it is a rose, that it has a beautiful odour, that it bears thorns, and are happy over the recurrence of an experience we know to be pleasant, which is perhaps bound up with happy memories of home, beautiful gardens, holiday trips, and so forth. All

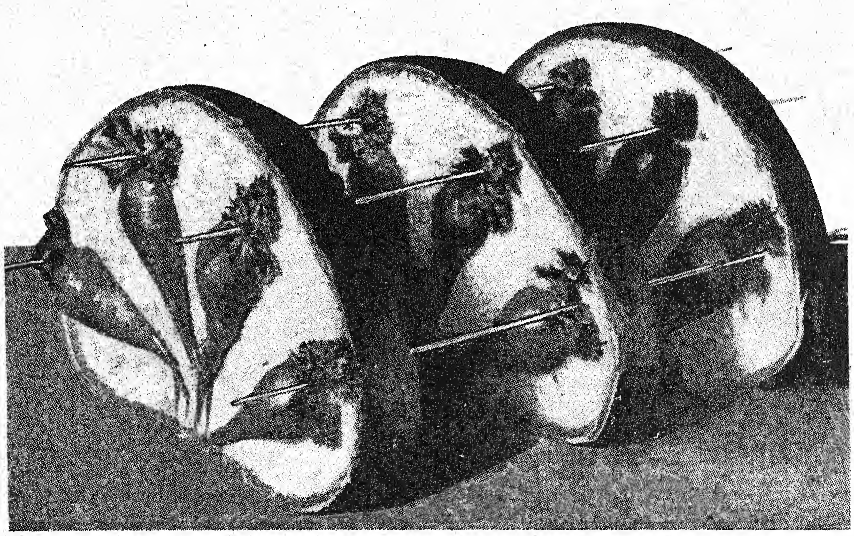


FIG. 283. *A model of the cerebellum, made out of radishes and slices of bread, fastened together with knitting needles. The slices of bread correspond to the leaves, or convolutions, of the cerebellum, the radishes to the equilibrating apparatus of the Purkinje cells. The needles represent the connecting "T" fibres. (See also Figs. 284 and 285).*

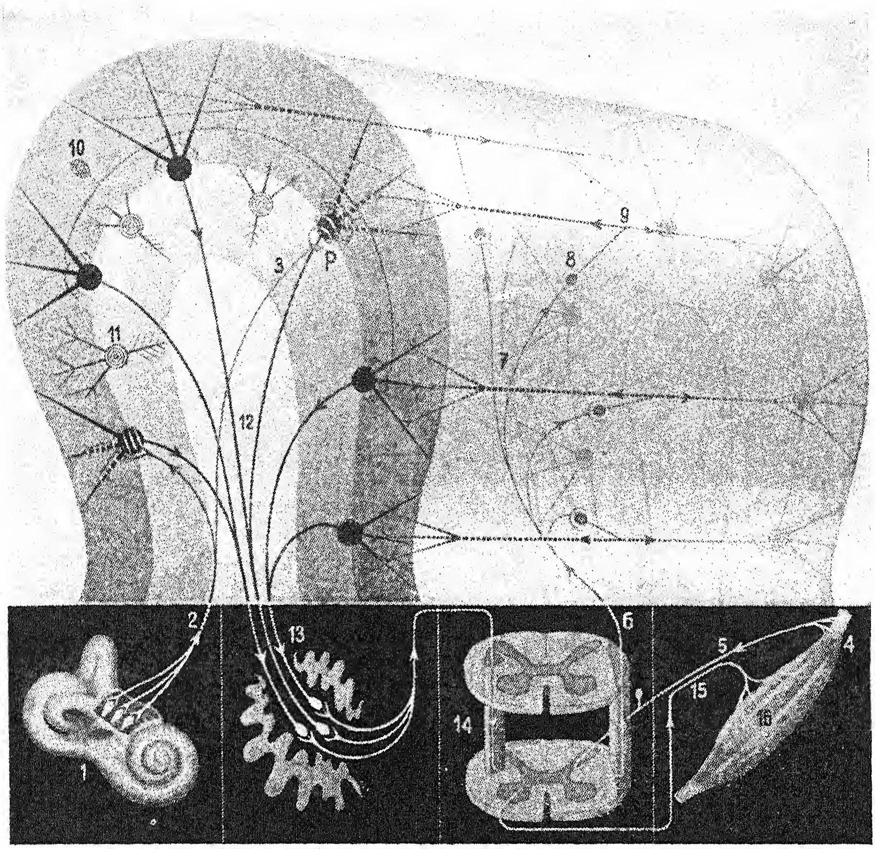


FIG. 284. *The cerebellum receives reports from the organ of equilibrium (1), and regulates muscular tension (16) through the equilibrium tract (13) and spinal cord (14).*

these mental processes occur in the cerebrum, not in the brain stem. A fish has no cerebrum. It is a brain-stem animal; it perceives only that which is momentarily present. In an hour it may perceive the same object and again tomorrow, yet each time it will be as new as it was the first time. Only animals with a cerebrum can be trained. At birth man is also a brain-stem creature. A newborn child cries when it is cold and protests when it is dazzled by a light. It experiences the present moment and everything passes by it without being retained, like a street scene on the focusing screen of an open camera. The brain-stem creature lives, but it does not have any lasting experiences; it has no memories of the past nor hopes of the future, but knows only the impressions of the present.

Instincts. Instincts are certain innate, stereotyped forms of behaviour in animals which are inherited because they are indispensable for survival and consequently function automatically. A newborn infant sucks at the mother's breast although

it knows nothing about food. A bird builds a nest suited to the number, size, and special needs of the coming young and hatches them although it has never seen a nest and knows nothing about birds' eggs. There are thousands of such instinctive actions.

The Animal in Man

The ganglia of the brain stem are the seat of instincts. Here resides everything that man has in common with animals, and which serves the primitive but fundamental purpose of preserving his existence. It is the animal in man. In contradistinction to the brain stem, the cerebrum is the part of the brain in which everything specifically human—that is, everything one learns after birth—is collected, and which contains all the knowledge and modes of reaction that characterize the adult individual. The brain stem embodies the innate characters wherein human beings are similar, while the cerebrum contains the acquired characteristics that differentiate them. The existence of interesting relations between the brain-stem personality and the "cortical" personality of the cerebrum has been discovered and investigated by modern psychology, especially by psycho-analysis and individual psychology.

Model of the Brain

The clear and revealing insights into the structure and mechanics of personality which have been obtained in consequence of these discoveries belong to the greatest achievements in the history of biology; indeed, they are among the greatest discoveries of science.

The Membranes of the Brain. Take a walnut, best of all a fresh one just picked from a tree [Fig. 286]. A walnut is a natural model of the human skull and brain: the green, fleshy outer shell is the skin (e); the hard, brown shell beneath it is the bony shell of the cranial cavity (d); the wrinkled kernel of the nut is the brain (a). In order to prevent the kernel from being flung against the wall, two strong supporting membranes are stretched across the interior of the nutshell, one vertically, the other horizontally. In the brain an analogous structure exists. The brain is also enveloped by supporting membranes. These are three in number and are known collectively as the meninges. The most external of these is the dura mater, a membrane which is very tough and strong, being composed of fibrous and elastic connective tissue.

Supporting Structures

The dura's outer surface adheres to the inner surface of the skull. At certain points within the skull the dura mater is folded to form two layers. These are similar in arrangement and function to the supporting membranes within the nutshell (c). By means of these layers both the nut and the brain are divided into four parts that are connected by bridges and girders of tissue. The white mass of the nut is enveloped by a delicate membrane that follows closely all the wrinkles and folds. Similarly, the innermost membrane enveloping the brain lies in immediate contact with the nervous tissue. This membrane, called the pia mater (b), is also composed of fibrous and elastic connective tissue. Thus it is apparent that both the walnut and the brain are protected and supported according to the same, almost ideal, principle.

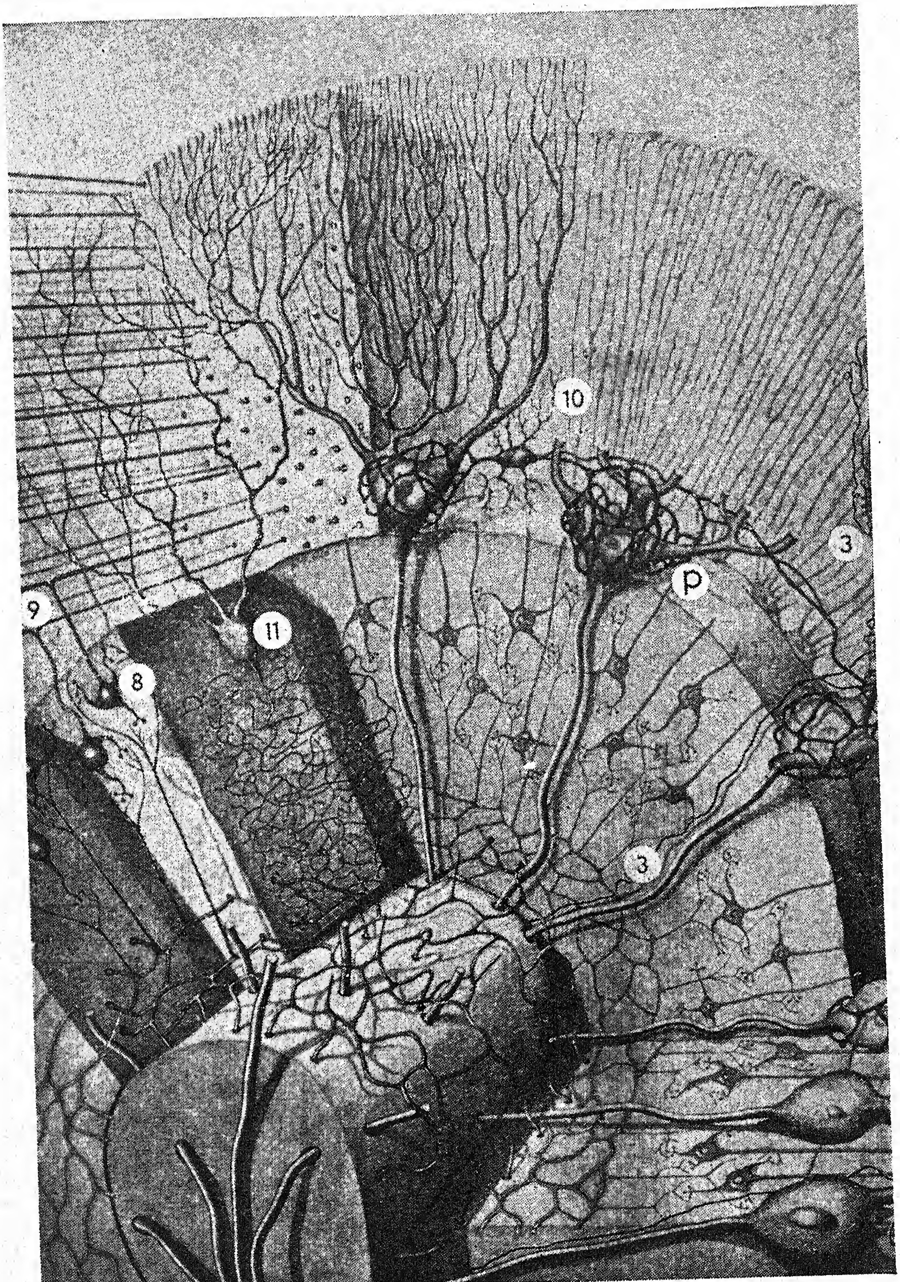


FIG. 285. *The microscopic texture of the cerebellum, showing its involved and delicate construction. The fragment of cerebellum shown in this picture, if reduced to its actual size, might be placed within the figure "o." Compare this illustration with Fig. 284.*

Inflammation of the Cerebral Membranes. In addition to their mechanical function the cerebral membranes contain the blood vessels supplying the brain. The vessels of the cerebrum shown in Figure 287 are situated in the pia mater and can be removed together with it. The space marked (g), which surrounds the cerebrum outwardly like the circumference of a circle, and also penetrates into the depths of the brain from (g) to (b) between the cerebrum and the cerebellum, is formed by a folding of the dura mater. It has been mentioned that at certain points in the skull the dura is folded to form two layers. Between these layers are spaces known as sinuses. During life they are filled with blood, for they communicate with the veins in that region of the body, thus forming part of the vascular system through which the venous blood flows. Thus the brain floats in blood. Since the cerebral membranes are well supplied with blood, they are a good culture medium for bacteria. If bacteria pass into the blood-stream, and thus into the cerebral vessels—for example, as a result of sinusitis, nasal furuncles, or middle-ear suppuration—an inflammation of the cerebral membranes, or meningitis, is produced. This is a very serious disease. In the first place, it threatens life directly because in half the cases the centres of metabolism, among them the respiratory centre and the blood-pressure centre, are compressed and put out of order by an accumulation of inflammatory fluid and pus. In the second place, the inflammatory process can damage the cerebral cortex and with it the personality structure of the individual in a disastrous manner.

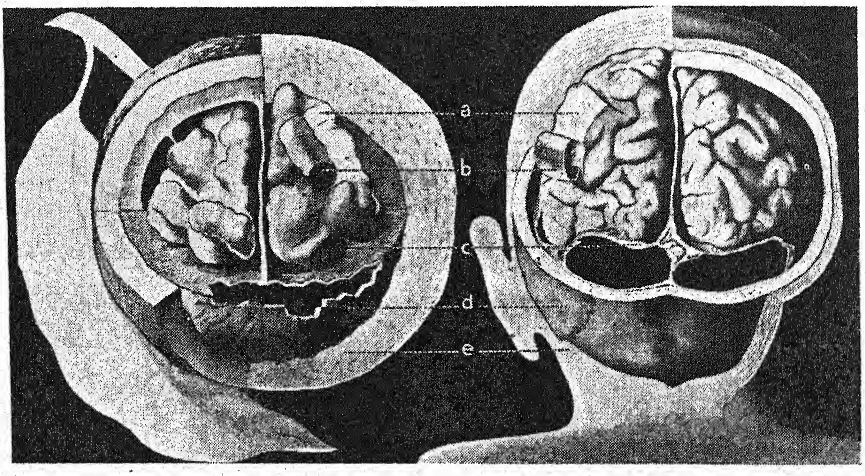


FIG. 286. *A walnut provides an admirable model of the human skull and brain. The mass of the brain and the walnut kernel are represented at (a); at (b) are the soft membrane of the brain (pia mater) and the soft skin of the nut; (c) is the hard membrane of the brain (dura mater), comparable with the tough skin of the nut; (d) represents the skull and the nutshell, while (e) is the outer, fleshy envelope.*

Headache. A headache is not a pain in the brain, but rather a pain

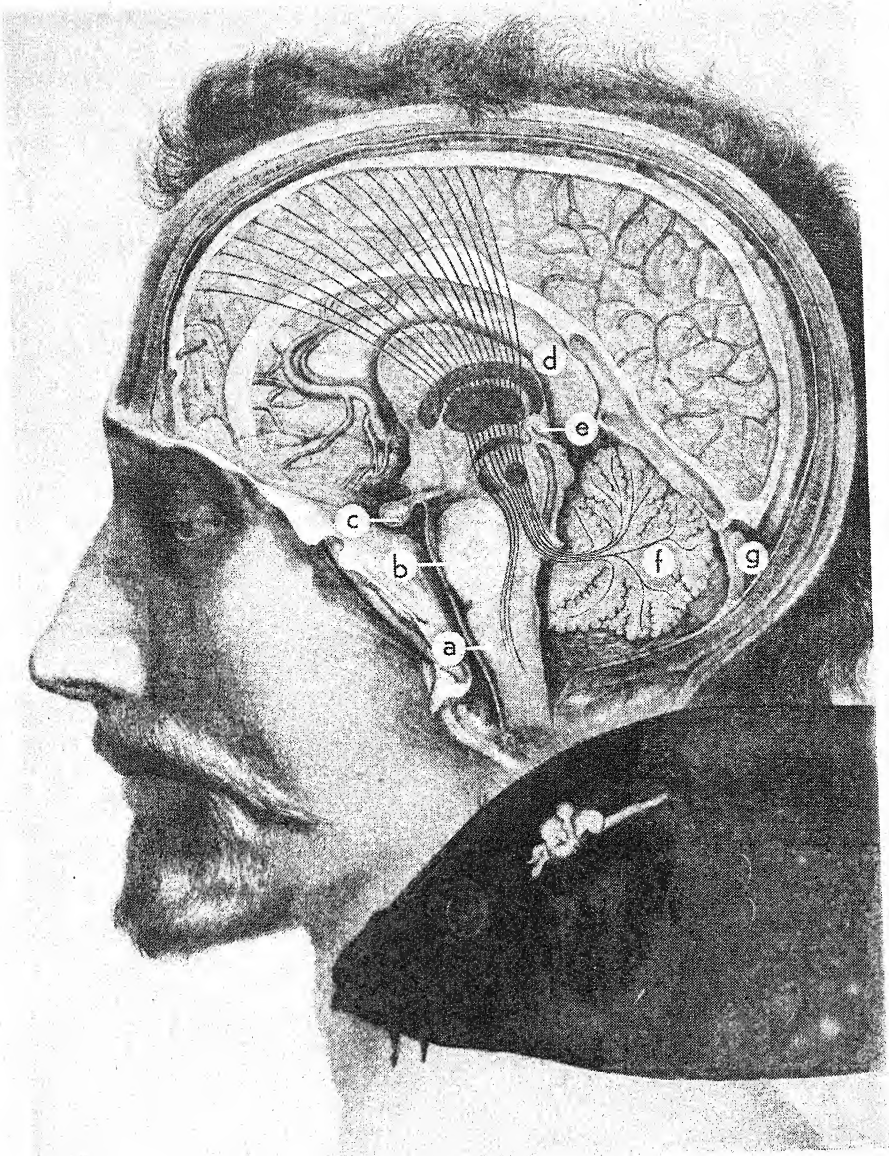


FIG. 287. *The brain of man compared with that of a fish. A fish possesses only the brain stem, the seat of the reflexes and instincts. Man, too, has this structure, which is the core of his "personality," but in addition he has the cerebrum, seat of the higher intellectual faculties. In this illustration are shown: (a) the medulla oblongata; (b) the brain stem—bridge between spinal cord and brain; (c) pituitary gland; (d) corpus callosum, connecting the two cerebral hemispheres; (e) pineal gland; (f) cerebellum; (g) vascular sinuses. The black areas and lines indicate the "extra-pyramidal system."*

in the very sensitive cerebral membranes. The brain is insensitive. An individual's consciousness can be removed in pieces, so to say, yet he feels no more than if one were to cut a button from his coat. However, with every piece of brain cut away a part of his consciousness is extinguished, like the illumination in a house where the lights are put out in one apartment after another.

By means of their sensitivity the meninges watch over the brain which they envelop, just as the peritoneum with its sensitivity to pain guards the insensitive organs of the abdominal cavity.

The Brain Fluid. The space between the dura mater and the brain is filled with fluid, the origin of

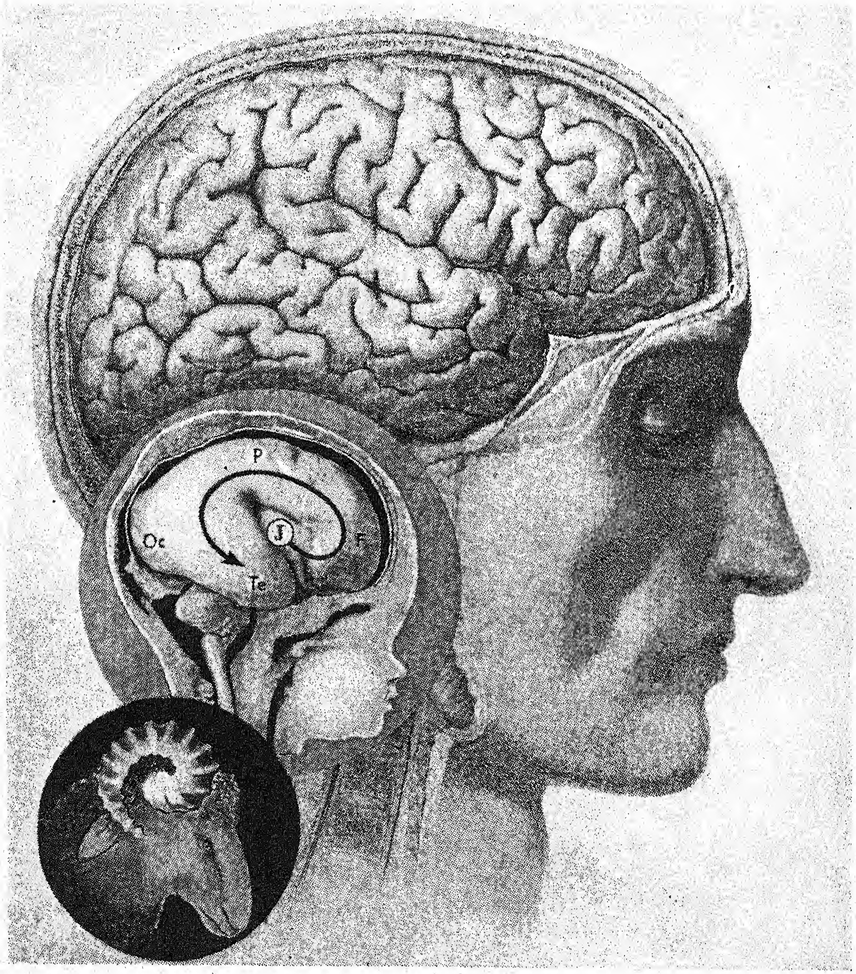


FIG. 288. *The cerebrum grows out of the island (J), spiralling round the brain stem like a ram's horn and thus forming the four lobes of each hemisphere; these are: (F) frontal lobe; (P) parietal lobe; (Oc) occipital lobe; (Te) temporal lobe.*

which was shown in Figure 140. The brain floats in this fluid — almost weightlessly! Take a loaf of bread in one hand and a letter in the other; outside the skull the brain weighs as much as the bread, and within the skull as little as the letter!

Dangerous Pressure

When the meninges become inflamed and secrete an inflammatory exudate, or when the heart and kidneys break down and excess fluid accumulates in the circulation, the quantity of brain fluid is increased, compressing the brain. This pressure on the brain produces headache, nausea, vomiting, stupor, and finally coma. These symptoms that are often an indication of danger to life itself can be relieved by bleeding, or by tapping the spinal canal and removing a certain amount of spinal fluid.

Hydrocephalus. Because of congenital disturbances in the circulation of the brain fluid, considerable amounts of fluid can collect within the child's cranial cavity, producing the condition known as hydrocephalus (water on the head). Extreme accumulations hinder the development of the brain and are one of the causes of feeble-mindedness.

The Cerebrum. In the animal kingdom from the fishes upwards, the cerebrum develops from the most anterior portion of the brain stem. Since it is unable to expand at will within the narrow cranial space, the new part of the brain grows in a loop, like a ram's horn, around the brain stem [Fig. 288]. The initial point of growth is the island (J). From this point the cerebrum first grows anteriorly (frontal lobe, F), then upwards (parietal lobe, P), now backwards (occipital lobe, Oc), and finally anteriorly again (temporal lobe, Te). The better developed the cerebrum, the more does it cover the island (J). In unborn children, in feeble-minded individuals, and in deaf-mutes whose temporal lobe is poorly developed, the island is exposed.

The Surface of the Brain. In lower animals and in the unborn child the surface of the brain is smooth. Later it becomes folded in order to accommodate an increase in size due to growth. Now the surface of the brain exhibits a series of elevated folds separated by depressed furrows or fissures. As a result of further growth the folds are pushed together and become twisted, giving rise to the sinuous convolutions that cover the surface of the brain [Fig. 288].

The Structure of the Cerebral Cortex. If one examines a cross-section of the brain such as that shown in Figure 280, one finds that it consists of a grey and a white substance like the spinal cord. Unlike the latter, however, the grey and the white matter of the brain are not arranged in the same way. The brain consists of a cortex of grey substance and a medulla of white substance. In the nervous system the cells are grey, the fibres white. Without using a microscope one can recognize by the colour where the cells are located and the course that the fibres take.

Brain Cells

The brain consists essentially of a mantle of cells distributed throughout the cortex and a nucleus of fibres that pass downwards from the cortex to the brain stem and the spinal cord. If one examines a microscopically enlarged cross-section of a

FIG. 289. *How the organ of the human mind appears under the microscope. The cells of the cerebral cortex, by means of which we feel, think, love, suffer, and reflect about ourselves with astonishment—as, possibly, the reader is doing at this moment.*

single convolution, one sees the fibres rising from the depths, and above them the cells of the cortex in several layers [Fig. 289]. The larger cells are shaped like pyramids and are therefore called pyramidal cells. In addition one sees still other types of nerve cells, as well as the glia cells that connect the nerve cells with the blood vessels and nourish them. In general six layers of cells are consistently found in the cortex of all mammals. In more highly developed animals the number is increased, in others it is decreased.

A Maze of Cells

In Figure 290 two microscopic sections of the human cortex are depicted as they appear in nature, in contrast to the schematized representation in Figure 289. Figure 290 I shows a section of the oldest and most primitive part, the olfactory area; III is a section of the most highly developed field, the visual sphere. Between them is a model II with the aid of which one can orient oneself in the maze of cells in I. At (a) are shown the cells of the first neuron, the olfactory cells in the mucous membrane of the nose (to be seen only in II, not in I; (b) is the bony wall between nose and brain, through the canals of which the fibres of the first neuron pass upwards to the brain; (c) are the filaments with which the first neuron terminates. At this level lie internuncial cells that connect the fibres with one another; (d) is the point of contact between the first and second neuron. The cells of the second neuron are the large pyramidal cells (e) in which the olfactory stimulus is probably perceived. From these pyramidal cells start the nerve tracts that fill the upper part of the picture. Between the large pyramidal cells lie small ones, and a similar layer of small pyramidal cells lies right underneath (f), beneath the cables. At the level of (g) lie rows of cortical cells in which the nerve fibres terminate. In contrast to all the other nerve cells of the sympathetic system, of the spinal cord, and of the previously described lower brain areas, these cells do not conduct the stimuli farther, but retain them. While all other cells can be described, technically speaking, as through stations, these are terminals. These terminals are the characteristic feature of the grey cerebral cortex. All other parts of the nervous system are apparatuses that receive stimuli or transmit them; in the cerebrum, however, layers of cells have developed that do not transmit stimuli, that do not exercise any visible function, but rather lead an independent existence which appears unnecessary when considered from the standpoint of function. The nerve cells of the skin, the viscera, the spinal cord, and the brain stem are telegraphers, telephone operators, surface-men, photographers, and radio technicians.

Art and Life

Water-mains, streets, electric lights, bread, and clothing are necessary. Pictures, books, music, and sculpture are unnecessary. The pictures of Raphael and Leonardo, the poetry of Homer and Shakespeare, the symphonies of Beethoven, and the philosophy of Plato are "superfluous" — but the "superfluous" things are the highest in life. How much of life would be worth living if all the books were burned, if all the musical instruments were destroyed, and all pictures cut to pieces?

If all the flowers were uprooted, if women were forbidden to ornament themselves, if stimulants were prohibited, and people were forbidden to climb mountains, to dance, to daydream in the sunshine, and to enjoy whatever other unnecessary but pleasant things there are in the world?

Personality

The nerve cells of the cerebral cortex are the most unnecessary of all the cells of the body. A creature can live without a cerebral cortex, but in these cells that are unnecessary for life the creature becomes conscious of its own self and the world; with them it recognizes and enjoys, it gathers memories and experiences, thinks and feels, speaks and writes, makes music and paints, dreams and loves—and suffers. They are life, knowledge, feeling, and enjoyment; they are the "I," the personality. "*We*" is the sum total of the cortical cells of our brain; our "*I*" is the giant concert which this greatest of all radio stations, this station of microscopic tubes, aerials, coils, condensers, and transformers, broadcasts as thought and feeling to the microcosmos of the cell body, and as word and deed to the wide world.

Brain Cells and Stars. Actually the two pieces of the cerebral cortex shown in Figure 290 are hardly as large as the space within this O, and they are thinner than the most delicate tissue paper. Together both pictures contain about 100 cells; the cortex of the human brain contains 150 million times as many. If one wanted to represent all the parts of the cortex in the same enlargement on pages of equal size, one would have to assemble a very large collection of books. A single bookcase would not suffice nor would an entire library room. Even a ten-room house full of books would not be enough, since one would have to print no less than 300,000 volumes of 500 pages each containing such pictures before completing the study of a single human brain! These are astronomical figures, and actually photographs of the cerebral cortex are surprisingly like stellar photographs [Figs. 291 and 311].

The Cortical Areas. When modern "micro-astronomers" began to examine the stars on the small heavenly globe within the skull, just as their colleagues in the astronomical observatories had been doing for several decades with the gleaming stars of universal space, they had a similar experience. They discovered that the brain cells, like the stars, are arranged in bunches and groups that they call cortical areas. The first stellar photographer of the human brain was able to delimit approximately fifty main areas, as shown in Figure 292. The modern generation of cell "astronomers" has increased this number to almost five hundred!

Increasing Refinement

At first the interesting fact was discovered that the brains of all mammals exhibit the same basic plan in the arrangement of the cortical areas. Then it was found that the cortical areas were also located in consecutive segments, like the segments of the spinal cord. Figure 292 shows the cortical areas of a bat (*Left*) closely related to the prosimians, of an ape (*Right*), and of man (*Below*). At first glance one recognizes the increasing refinement and complexity of the cerebral cortex in the course of evolutionary his-

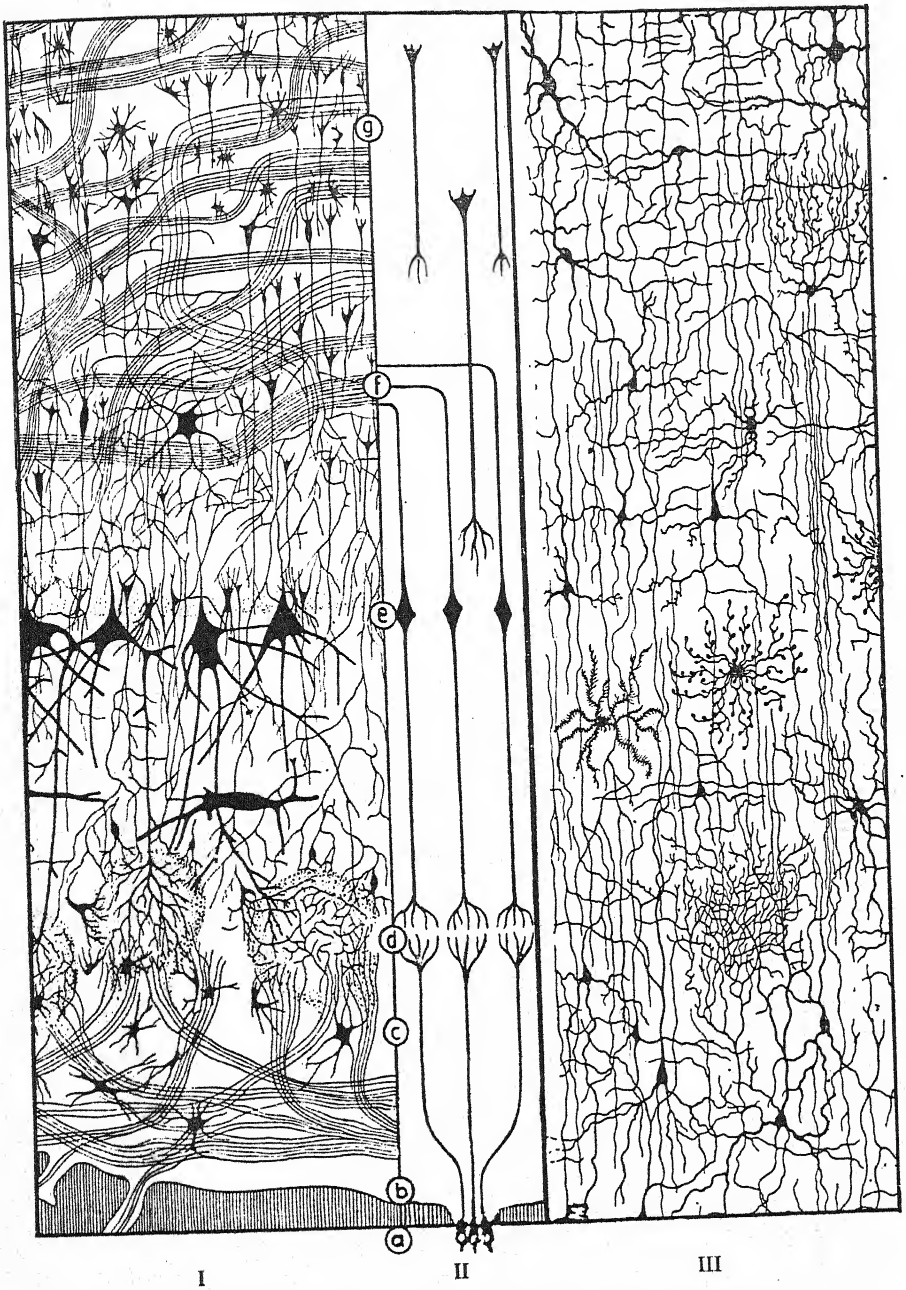


FIG. 290. *Sections of the olfactory cortex (I) and the visual cortex (III) of the brain. By means of the cells at (I) we detect odours; those at (III) enable us to see. At (II) is a diagram by means of which one may thread the maze of cells (Page 421).*

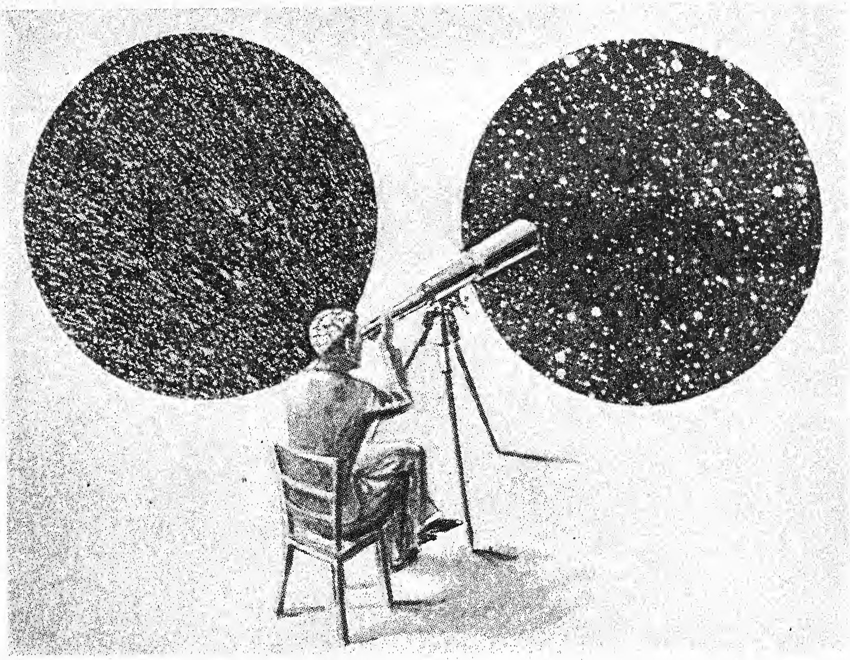


FIG. 291. *The minute universe of the human brain observes the vast universe of interstellar space. In man's brain are fifteen thousand million cells; in the Milky Way there are as many suns. Between them, comprehending neither the one nor the other, is man, whose intellect has discovered both.*

tory. The ape brain has twice as many areas as that of the prosimian, while that of man has twice as many as the ape. Then, too, one recognizes the characteristic shifting of the areas. The area with the large black dots (4) is the motor centre—that is, the cortical area with the motor cells that send action currents to the muscles through the pyramidal tract. As the wandering of the arrow with the number 4 clearly indicates, in the course of the evolution of the brain this area has moved from the anterior pole of the brain to its middle, for in front of it has developed the extensive region of the frontal lobe (indicated by the broken line) with approximately 100 cortical areas. These areas of the frontal lobe have as yet been little investigated. In their totality, however, it is believed that they are the material basis of all that we describe as character and temperament in man. The large bundles of nerve fibres that exert an inhibitory influence on the reflexes of the brain stem and the spinal cord originate in the frontal lobe.

Inhibitory Fibres. Common to all animals is the grasp reflex, which in man has been restricted and transformed to the plantar reflex. If a dragonfly settles on a plant stem, its feet automatically clinch around its perch owing to the grasp reflex, and it remains attached to the stem for hours without having to exercise its will, and consequently without tir-

ing. If the dragonfly wants to fly away, it must interrupt the grasp reflex, and for this purpose sends a nerve impulse from the brain to eliminate the reflex. Nerve fibres that eliminate or break reflexes are called inhibitory fibres. If the head of a perching dragonfly is cut off, it cannot interrupt the reflex and remains on its perch until it dies. Snails and caterpillars crawl automatically without exercising any volition. In order to stop, they must eliminate the crawl reflex. When decapitated, they continue to crawl without stopping.

The Essence of Training

The grasp reflex is still quite strongly developed in very young children. If one gives a child a finger, it grasps it firmly and does not release it. In so doing, the child is carrying out a very ancient animal reflex, the grasp reflex, by means of which young mammals hold fast to the mother's skin. If one gives a two-year-old child a pencil, it holds it tightly. It is part of the educational programme of the school to weaken and inhibit this grasp reflex so that the child will be able to hold a pencil and write with it. The major portion of the education that human beings receive during the pre-school years, in school, and in later life, consists in the development of inhibitory fibres and inhibitions in order to overcome reflexes. A newborn child cries when it is hungry. It must get used to eating only at meal-times, so one of the first things a child learns is to suppress the reflex to cry when hunger pangs appear. Then a child is taught to be clean. It must learn to inhibit the bladder and intestinal reflexes, and to let them function only at certain times. This is the beginning of training for life, and this is how it continues for ten, twenty, thirty years under the constant motto: "Develop inhibitory fibres," so that training may be said to be equivalent to the possession of inhibitory fibres and the ability to control one's reflexes, urges, and animal instincts by means of them.

General Paresis. The important part played by the inhibitory fibres in human life may be recognized from the effects produced by alcohol (see Pages 338-342), and also by certain mental diseases, pre-eminently general paresis, in which, as in alcohol indulgence, the inhibitory fibres are affected first. General paresis, like tabes, is a late form of syphilis. About fifteen to twenty-five years after the primary infection, either the conducting fibres of the spinal cord or the cells and fibres of the cerebral cortex degenerate and vanish. This occurs in approximately three to six per cent of uncured cases. The disappearance of the cells first becomes evident because of the missing influence of the inhibitory fibres.

Relaxing Control

The normal civilized individual who is restrained by his inhibitions can be compared to a traveller who returns from Africa bringing a valise full of snakes with him. He takes care not to let the people around him know about his dangerous baggage, but travels in the train, reading a paper, as if his baggage contained only such harmless things as clothes or books. The uninhibited paralytic, however, opens his valise, letting the imprisoned beasts creep out. Thirst for power, vanity, megalomania, avarice, greed, boast-

fulness, and so on, appear undisguised. Just as in the case of a drunken man, whose cells are not destroyed but only temporarily paralysed, actuality is cleared away with a wave of the hand by eliminating all inhibitory criticism, and is replaced by a fantastic dream world.

Megalomania

The patient calls himself "Prince of Navarre," hangs a paper order on his chest, and is proud of his "decoration." A tin can upon his head becomes a golden crown, and he tells stories about millions of subjects who serve him on Mars and Jupiter and will descend to earth tomorrow to do homage to him as the Lord of the World. With the progessive destruction of the cortical cells this megalomanic phase comes to an end, because the degeneration of the cells is accompanied by the disappearance of all memory of persons, things, and words, and by the vanishing of imagination. The ability to express himself is diminished, words are confused, mistakes in writing increase, the vocabulary becomes smaller, and the paralytic succumbs to an increasing impoverishment of his mental life. Finally, complete dementia supervenes.

The Motor Centre. At the top of the brain lies the so-called precentral convolution [Fig. 292 (4)], which contains the cells for voluntary muscular excitation, the motor centre. This area must be a true technological miracle, for the motor cells, approximately a million of them, are arranged in the exact sequence of the limbs and muscles. If pictures of the limbs controlled by them are superimposed on the motor cells, one sees the right half of the body on the left side of the brain, and the left half on the right side [Fig. 293]. If each cell connection had an electric bulb that would light up whenever the cell sent out a current, like the lights on the switchboards of electrical circuits, the various parts of the brain representing different organs would light up like electric signs, depending on which organ was functioning.

Apoplexy. An apoplectic stroke is a calamity that falls like a bolt from the blue. A blood vessel tears in the brain, usually in the region of the internal capsule [Fig. 293 (J)]; the motor centre above the bleeding area receives no blood and stops functioning, and the victim is paralysed on the side of the body opposite to that where the lesion is located and falls down in an apoplectic fit. The internal capsule is the narrow defile through which the motor fibres of the pyramidal tract pass on their way from the motor centre to the spinal cord. Within the internal capsule the fibres are crowded together. Here the fibres radiating from the cerebral cortex come together and begin to form cables. Indeed, the internal capsule must be the most complicated cable known to technology, for here the fibres combine to form tracts without giving up their sequential arrangement by regions and organs.

Feeling with the Brain

Apparently the blood vessels at this traffic junction are exposed to a very great strain, for they age earlier here than at other points in the brain. More than half of all hæmorrhages in the brain occur in the region of the internal capsule.

The Sensory Sphere. Behind the motor centre (4) in Figure 292 lies

the area of sensation (1, 2, 5, 7). One cannot speak of a sensory centre, for we are dealing with an entire series of fields in which the various sensations such as pain, temperature, and touch are localized next to one another. In the cells of this area we become conscious of the stimuli arising from the external world. We have the idea that we feel with our fingers, but actually the fingers are without feeling. If the sensory fibres between the arm and the brain are severed, one can put a hand into a fire and feel as little as if one were to witness the burning of a piece of wood. The hand possesses only receiving apparatuses, antennæ for the various stimuli of the external world; the radio receiver that reproduces these stimuli is located in the brain stem; and the person who hears them is situated in the cerebral cortex in the form of a cell, as shown in Figures 266 and 294. The cells of the sensory area are arranged in rows like the levers of an indicator box. Let us imagine that we are in the service room of a hotel and are observing the activities there. Number 62 appears on the indicator. "Professor Miller wants his coffee."

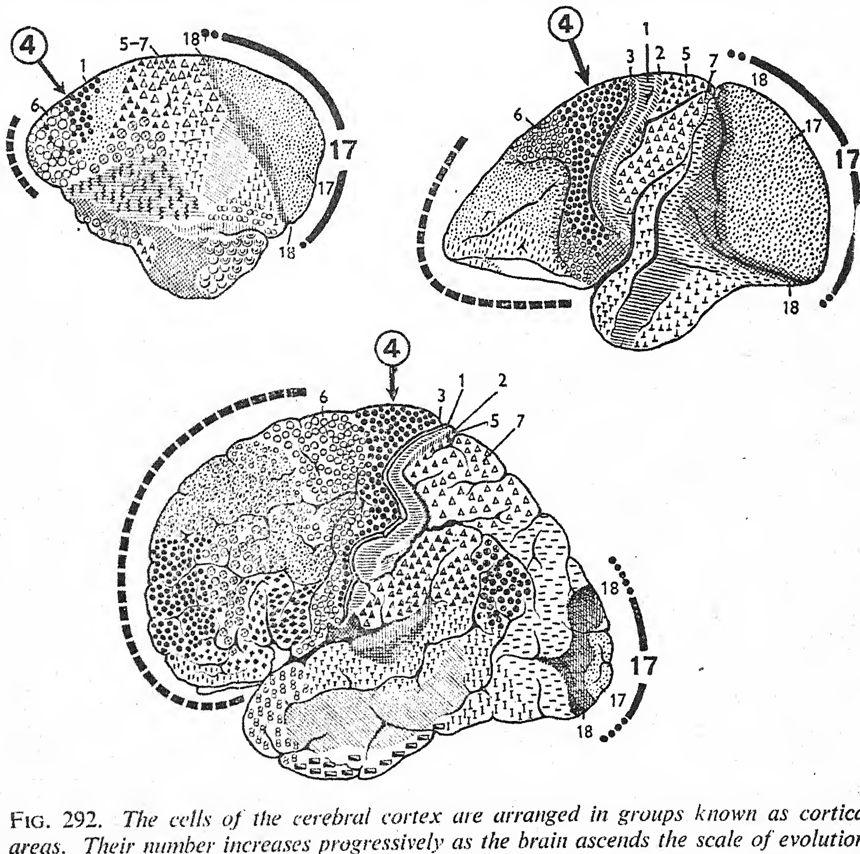


FIG. 292. *The cells of the cerebral cortex are arranged in groups known as cortical areas. Their number increases progressively as the brain ascends the scale of evolution, but their basic arrangement is the same in all mammals. (Left) The cortical areas o' a bat related to prosimians; (Right) those of an ape; (Below) those of man.*

the woman in charge calls to the kitchen. To be sure, all she sees is that number 62 has appeared on the indicator, but she knows from experience that number 62 is a room on the third floor, that Professor Miller lives there, and that when he rings at 8.30 a.m. he wants to have his coffee. Now number 5 appears. "Has the medicine for the child come from the chemist's?" she asks, because she knows that there is a sick child in room 5. Then number 0 appears in the indicator box. "John," she cries, "there are newly arrived guests outside." She doesn't see them, but she knows that when

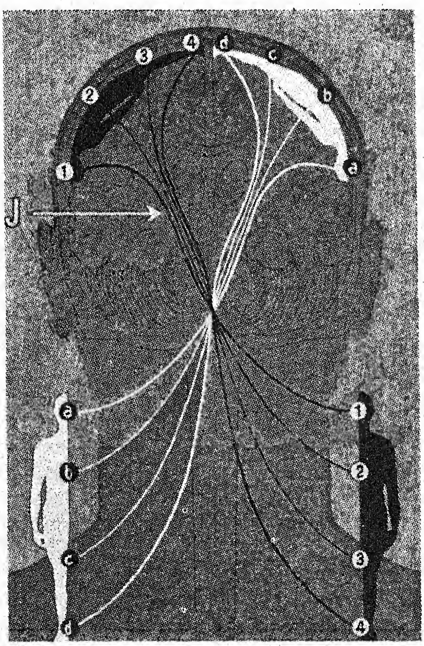


FIG. 293. *The motor centre. The motor cells for voluntary muscular contraction are located in the parietal area. They are arranged in an inverted mirror-image order. At (J) is the internal capsule, the location of most cerebral hæmorrhages (apoplexy). In the centre can be seen the crossing of the pyramidal tracts.*

number 0 appears, there is someone outside, and that about this time the night train arrives with new guests for the hotel. We can compare the brain to such an indicator box. "We" means our brain cells. Our brain cells, however, are imprisoned within the dark space of the cranial cavity, from which they never emerge. The optic cells of the cerebral cortex never actually look out of the windows of the eyes, and the auditory cells never come into contact with sound waves of the air. These cells live at the end of the long, dark corridors of the Hotel "Brain," in the dark offices that we call centres. Here they are born and here they die as eternal prisoners, galley slaves of the indicator boxes where the fibres terminate that come from the sense organs to the interior of the brain.

By long experience the cells are trained to know that there are guests in front of the hotel when 0 appears in the indicator, and that John must now be called to take care of them—yet they themselves never see either John or the guests. We can also compare the brain cells with the cooks and butchers that work in a large ocean liner. They see neither the tables nor the passengers, but only receive orders from which they infer the number of travellers, which tables are occupied and which are unoccupied, when there is a celebration, and when the passengers are seasick in their cabins. We learn nothing about the world apart from what the nerves conduct to the cells of the cerebral cortex—namely, an enormous number of nerve currents and signals of various kinds, which we receive through our sensory apparatus and which we learn to decipher and to answer correctly on

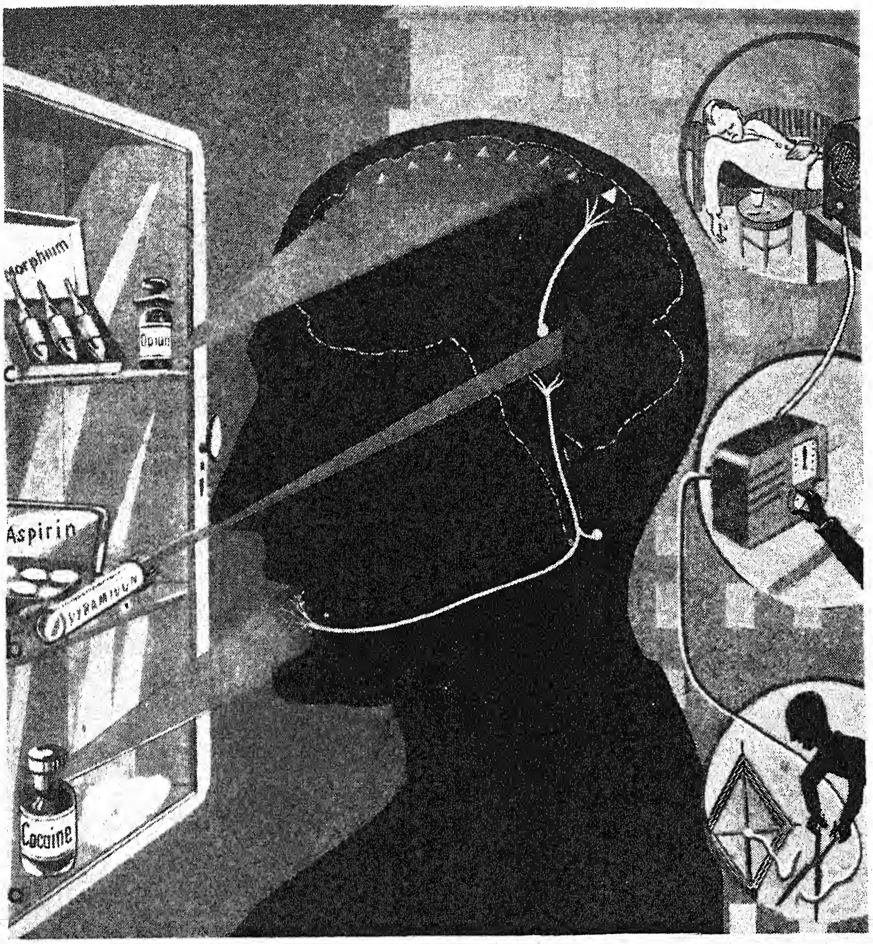


FIG. 294. *How narcotics deaden pain. Cocaine (a) interrupts the connexion with the antennæ which receive stimuli at the surface of the body. Aspirin, amidopyrine, quinine, etc. (b) switch off the pain-producing apparatus in the brain stem. Opium, morphine and codeine (c) narcotize the sensory cells of the cerebral cortex.*

the basis of experience and education. There is no direct, "absolute," and consequently "true" knowledge of things outside of our consciousness. Each creature can only perceive as much of the world as impinges upon its sense organs, and can recognize so much in its *own* way only in so far as its cortical cells are able to sort out these stimuli. We learn nothing of "things" as such, but register only the *impression* of things on our consciousness, their emanations, their effect on our nerves—something entirely secondary and subjective. This recognition is the beginning of all philosophical insight and the fundamental idea of the theory of knowledge that Plato immortalized in the famous description of the cave. We stand in the darkness of the night before

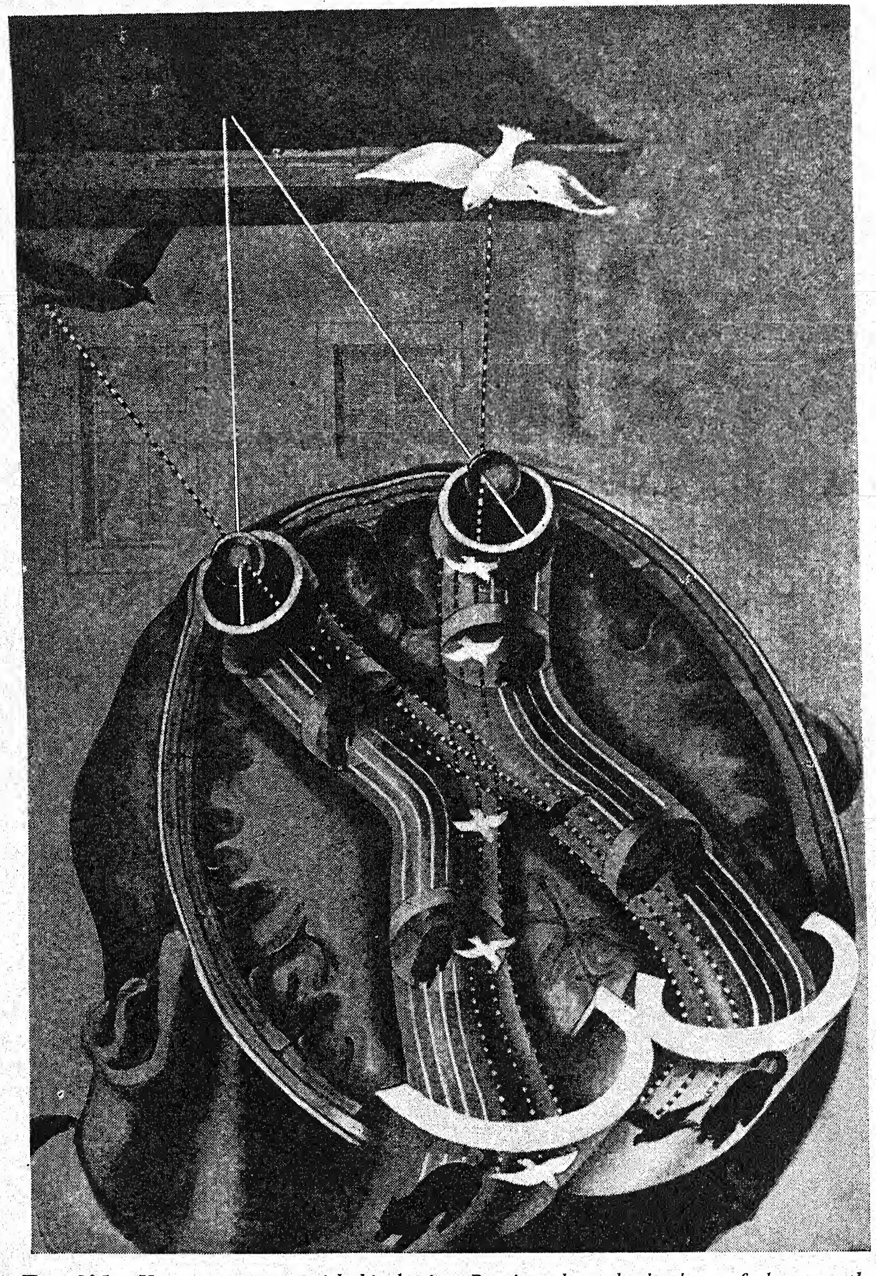


FIG. 295. *How man sees—with his brain. Passing through the lens of the eye, the image is projected upon the retina, where light impressions are transformed into electrical impulses of varying strength. These impulses are conveyed by the fibres of the optic nerve to the visual areas of the cerebral cortex, where they produce a stimulus image.*

a cave in which a fire burns. We see shadows on the walls, and infer from the shadows that there are men in the cave who are moving about, but we do not see the men themselves. Most philosophers after Plato have accepted this fundamental idea; and Schopenhauer has even included it in the name of his chief work, which begins with the sentence that has acquired an everlasting value for thinking men: "The world is my idea. . . ."

An Illusory Limb

The Phantom Pain. The phantom pain furnishes a medical illustration of this theory of knowledge. On December 10 a man's foot is seriously injured in an explosion. The leg is amputated at the thigh. Up above in the indicator box of the sensory sphere the indicator for the foot appears: the foot hurts . . . the foot hurts . . . the foot hurts. The leg is no longer there, but the connection from the foot rings incessantly in the brain, and the man lies in bed complaining of pain in a foot which no longer exists. When someone asks him: "Where does it hurt?" he points to a spot on the bed where his foot would lie if he still had it. The doctor consoles him: "Just have patience for a few weeks. In January the nerves will heal." Indeed, the pain actually subsides, and in February the patient stands happily before his doctor, and laughs at the "phantom pain."

In September he awakes at night. He feels the sheet: he has his leg again! It hurts once more. He clearly feels that his foot is there, he feels the big toe and an itching of the instep. He must scratch it, and scratches the sheet. During the next night the pain recurs, and now his leg also hurts during the day, the leg which has been gone for almost a year. He goes to the doctor. "You have a neuroma, a nodule at the end of the severed nerve, which is irritating it." The nodule is removed, and with it disappears the irritation of the nerve. Up above in the indicator box of the sensory area the indicator for "foot" no longer appears, the pain and the feeling of the continued existence of the foot diminish, and the man is finally rid of his leg that he lost a year before. To be sure, he had lost his leg at the thigh, but not up above in the cerebral cortex, where everything, including one's own leg, is reflected as an "idea."

Analgesics. To eliminate the idea "pain" there are three possibilities [Fig. 294]. One can eliminate the first neuron that receives the pain at the periphery of the body—that is, the antenna (a). Hot or cold compresses, mustard plasters, and salves containing cocaine are such "antenna" remedies.

Narcotics

Secondly, the connection between the organ and the brain can be interrupted by substances that paralyse the switch mechanism in the brain stem (b). The best-known substances of this group are quinine, aspirin, and amidopyrine. Thirdly, the sensory cells of the cerebral cortex can be paralysed. Substances that narcotize the cortical cells are opium, and morphine, which is obtained from it (c). Employing the comparison of the sensory path with a radio installation, as in Figure 294, one can say that cocaine interrupts the connection with the antenna, amidopyrine turns off the

radio, and morphine puts the listener to sleep. The well-known differences in the effects produced by these three substances is explained by the fact that they act at different points. Morphine, opium, and its numerous derivatives such as codeine make a person feel tired because they paralyse not only the pain area, but also the entire cerebral cortex—above all, the neighbouring motor centre. They weaken the will and the vision and put the individual into a kind of dreamy, somnolescent state. If a person has become accustomed to these substances as a result of habitual use, they act like alcohol on a chronic

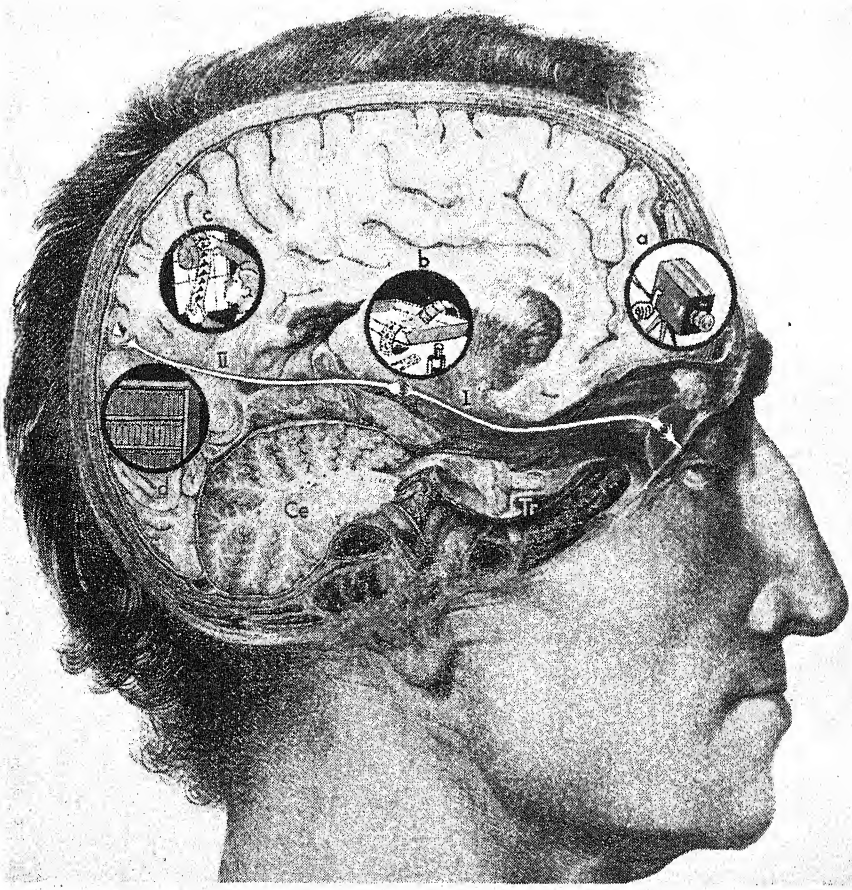


FIG. 296. *On its way from the eye to the occipital area of the brain, the visual image passes through four stations: (a) the eye photographs the object and sends the image in the form of an electrical current to the brain through connexion (I). In the optic thalamus (b) the stimulus image is developed and then is sent through connexion (II) to the occipital lobe. Here the pyramidal cells of the cerebral cortex (c) become cognizant of the image. Cognition (the act of recognizing) is accomplished by means of the "records" stored in the archives of optical memory (d).*

alcoholic. Instead of producing a paralysing effect they act as stimulants, and like alcohol create a state of intoxication, which is characterized by the vividness of its dream pictures (opium intoxication). When used habitually for long periods, these substances damage the cortical cells and the inhibitory fibres, thereby changing the personality in a disastrous manner (morphinism).

Sight and Television

The brain-stem drugs (aspirin, amidopyrine, and quinine) can never produce such effects because they do not act at all on the cerebral cortex. On the other hand, however, they act on the neighbouring metabolic centres, pre-eminently on the temperature centre by lowering the temperature of the body. On this account they are used not only to relieve pain but also to fight fever.

Vision. Behind the sensory area in Figure 292 lie Fields 17 and 18, the area of the optic cells, those cells of the cerebral cortex in which we experience the images of the external world. The visual apparatus of the vertebrates exhibits an astounding similarity to a television machine. The eye is a camera. Its optically sensitive plate is divided into a network of fields like the receiving plates of certain television apparatuses. Just as in a television apparatus, each field contains a cell which is sensitive to light. By means of these cell fields the perceived image is broken up into a million light points, each producing a stronger or weaker current in the cell, depending on its brightness. Thus the eye, like the television instrument, is a photo-electric mechanism, which transforms light impressions into electrical currents. But while the television apparatus sends these current impulses by wireless transmission over great distances—in this respect it is superior to the eye—the eye transmits them by means of cables—that is, by means of the two million fibres that make up the two optic nerves of the brain. The path of the image points can be traced in Figure 295. The birds are situated laterally in the visual field and are consequently projected on the inner half of the eye. Their images pass through the internal crossed fibres of the optic nerve (broken lines) to the opposite half of the brain. On the other hand, the image of the cat, which is located in the centre of the visual field and is seen by both eyes, is projected on the outer half of the retina of each eye. The image current passes through the external uncrossed cables (white lines) to the visual areas of the corresponding brain halves.

At its posterior end the optic nerve breaks up into its component nerve fibres. Each fibre ends in a cortical cell, and the totality of these cells forms a counterpart to the retina of the eye, a "cortical retina." The order and intensity of the stimuli received by the cells of this "cortical retina" are the same as those that stimulated the cells of the retina, thus giving rise to a stimulus image in the occipital cortex of the brain which corresponds to the retinal image.

Camera of the Eye

Ocular Blindness. The nerve tract between the eye and the occipital area is composed of four neurons [Fig. 296]. The first neuron is the retinal cell in the eye. With this neuron we take pictures of the ex-

ternal world. It corresponds to the sensitized plate of a camera. We are accustomed to saying that we see with our eyes, yet actually we do not see with them but with the cortical cells of the occipital lobe. We only take photographs with our eyes. Our eyes are a stereoscopic camera built into the skull, with which we photograph the various events of our lives (a). If a person loses his eyes, he is like a photographer who has lost his camera. He can no longer take any photographs; he is blind.

From Stimulus to Image

The Optic Thalami. The first of the two long intermediate neurons (I) extends as far as the brain stem and terminates here in a nerve hillock, the optic thalamus. In the lower vertebrates (fishes, frogs, lizards) the optic tract ends here. The optic thalamus is the seat of primary vision. Among the higher vertebrates it is only an intermediate station, where the stimulus is, in some manner as yet unknown to us, turned into an image, a process analogous to the development of a film in a dark room (b). This image is now carried by the next long neuron (II) to the cerebral cortex. Here in the form of the cortical cell is the photographer who looks at the strip of film (c), exposed by the ocular camera (a) and developed by the optic thalamus (b).

Cortical Blindness. If the cerebral cortex in this area is injured, the affected individual is also blind. To be sure, the eyes are intact; they take pictures as before and these pictures are developed in the dark room of the optic thalami, but the photographer in the studio at the back who has to judge the pictures is dead. Cortical blindness is a condition often observed after severe injuries to the occiput, especially in consequence of gunshot wounds and injuries produced by shell fragments.

The Optical Memory Centre. Next to Field 17 in Figure 292 we see Field 18. Here are situated the cells of optical memory; or to continue the analogy of Figure 296, here are the photographic archives (d). To obtain a clear understanding of the difference between the two fields, look at this page. This act is carried out by means of the path from (a) through (b) to (c). Now close your eyes and try to imagine the appearance of the page; this internal vision is made possible by the cells of Field 18 in Fig. 292. Field 17 sees the world; in Field 18 the optic stimuli are impressed as visual memories. At night when we dream with closed eyes, we certainly don't see anything. The path (a) to (c) is as inactive as a television set that is not in use. However, from the depths of memory emerge the optical impressions of Field 18, and these are our dreams.

Memory Archives

In the archives of our optical memories are stored many thousands, even millions of impressions. Everything that we can visualize while our eyes are closed is deposited in these archives. Close your eyes and try to recall the many visual memories that you possess. Begin slowly with your memories of your life. Recall the people with whom you have become acquainted, then the towns, streets, houses, and gardens that you have seen. Try to see how many plants, animals, how many buildings, works of art, books, machines, household articles, num-

bers, and words can be gathered from your memory collection. All this wealth of memory is somehow impressed and contained within the memory centre, but we do not know how this is done.

"Memory Blindness." If Field 17 is destroyed, an individual can no longer perceive anything; he is suffering from cortical blindness. If Field 18 is destroyed, he can still see, but he no longer has any optical memory. He sees, but he no longer recognizes anything; he is affected with "memory" blindness. Nietzsche was affected in this way, and so is the old woman in Figure 297. She sees the sponge but cannot recognize it. If she is permitted to touch the sponge, she recognizes it by means of her sense of touch just as we would recognize a sponge in the dark. A person with "memory blindness" sees a clock. On being told that he is standing in front of a clock he must touch and feel the hands of the clock before he is able to tell the time. The daughter of such a man enters his room, but the father does not recognize her. Not until the "something" that stands before him begins to speak is it possible for any connection to be established between them.

The arrangement of the visual memory centre is as orderly as that of a good photographic library. The pictures are arranged according to subjects. In a manner of speaking, there are departments for colours, forms, numbers, letters, etc. Because of this orderly arrangement the destruction of some parts may leave others entirely uninjured. Owing to a cerebral hæmorrhage an industrialist completely lost his ability to read and was only able to speak and write in a very defective manner. However, he retained his memory for numbers. He came to his office every day, was present at all discussions, and indicated his agreement with certain prices by writing down the numbers. One day he changed his will. In order to determine the legal validity of this act a psychiatrist was called. The psychiatrist read the testament aloud in the presence of the industrialist and intentionally made an

FIG. 297. *Memory blindness. This old woman has lost her optical archives [Fig. 296 (d)]. She can still see things because stations (a), (b) and (c) are preserved, but she no longer recognizes the objects which she sees. However, on touching the sponge, she recognizes it, just as one would do on touching an object in the dark.*

error in reading a certain sum. At this the man jumped up and pointed out the sum that the psychiatrist had read incorrectly.

Education means the development of such centres in the brain. When a child learns to read it starts a collection of letter images near the visual centre so that it becomes able to distinguish these letters. Then it learns that the letters are arranged in certain patterns, syllables, which it learns to combine into images of whole words. Then it reads words —at first short ones; later, when it can read better, long ones, too. In this way it enriches its reading centre, until it carries a collection of several thousand word images in its brain. During the school years the individual becomes aware of the fact that words occur in combinations that are constantly repeated, and learns to comprehend them at a glance, so that slight reminders suffice to bring about a recognition of large groups of words. An uneducated person has to work over a sentence as if he were cutting a path through a dense thicket, while one who reads a great deal simply flies over the lines. Reading

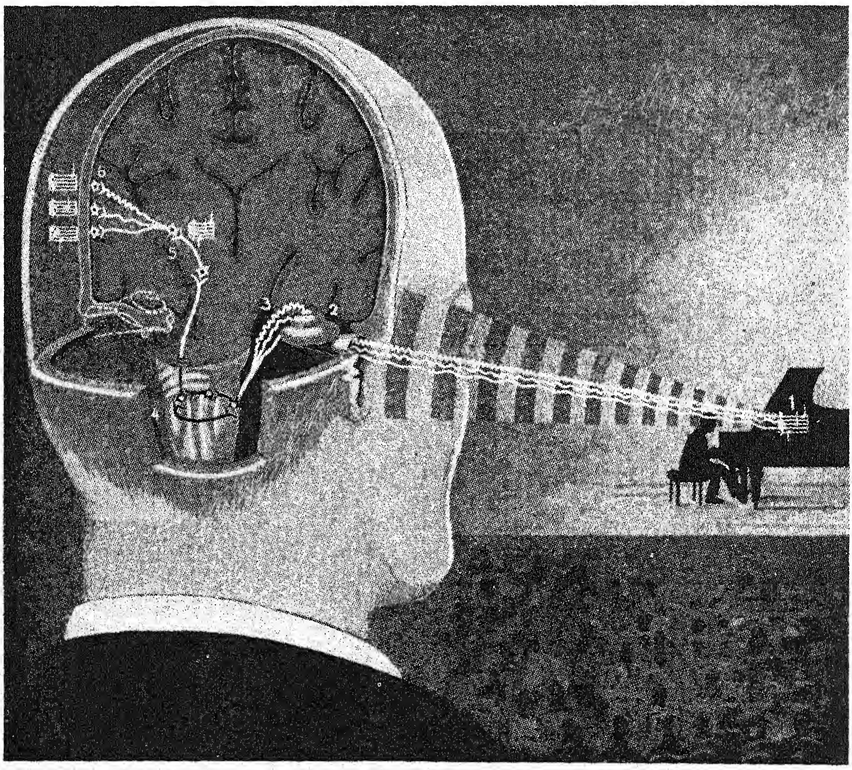


FIG. 298. *This is how man hears—not with his ears, but with the temporal cortex of the brain. The sound stimulus (1) passes through the cochlea (receptor membrane) (2), downwards (3) into the medulla oblongata, over to the opposite side (4), and then to the temporal lobe (5) and the apparatus for apprehending individual tones (6).*

specialists and reading geniuses can comprehend entire paragraphs, even entire pages, at a glance. There have been reading geniuses who read through an entire book of dictionary size in a single day and even indicated typographical errors. Monks, Talmudic scholars, students of the Koran, and others who have read stereotyped texts daily since earliest youth have an image of every page in their heads. On the basis of this visual memory image in the brain they are able to recite, not only forwards but also backwards, psalms or sections of the Koran from memory.

Number and Word Images

"Memory Wizards." The accomplishments of "memory wizards" are due to this ability. At the dictation of people in the audience they write rows of numbers in the form of a chequer-board square on a blackboard. The audience copies the numbers. The "calculating wizard" looks at the blackboard for ten seconds, but without memorizing the rows of numbers. Instead, he obtains an impression of the total visual image. Then he erases the numbers on the board, and reads them from his memory image, adding and subtracting more rapidly than the audience can follow.

The Writing Centre. When we wish to write a word, we first obtain a mental representation by fetching it out of our archive of memory images. This word image is sent to a special writing centre where it is transformed into a pattern of stimulus impulses. This image is carried to the cells of the motor centre and activates the muscles of the hand.

The Centre of Auditory Perception. Sound impressions [Fig. 298 (1)] pass through the ear (2) by way of a receptor neuron (3) into the medulla oblongata (4). Here the stimulus is transferred to neurons of the opposite half of the brain and conducted upwards to the temporal lobe (5). This part of the brain contains a special centre for the reception of sound stimuli, the auditory sensory centre (6). It contains cells that perceive sounds of varying pitch and quality. Actually we do not hear with the ears, which are only organs for the reception of stimuli. We hear with the cortical cells of the opposite temporal lobe. If this centre is destroyed the individual becomes deaf. There is a special centre for the reception of harmonious sounds and another for noises.

The Auditory Memory Centre. In the auditory sphere, just as in the visual sphere, repeated perceptions are stored as impressions, memories. In the occipital lobe a person carries a photographic archive, while the temporal lobe contains a collection of "gramophone records." When a person learns a second language he accumulates another collection of records, and one who speaks five languages may be thought of as possessing five such collections.

Forgetting a Language

Memory Deafness. A Frenchman came to England, learned English, and later resided in Paris as a language teacher. One day, as a result of an accident, his speech centre was injured, but only the area controlling the vocabulary of his mother tongue was destroyed. With the destruction of the centre he lost his memory of the words deposited here, his knowledge of French. The centre controlling his knowledge of English remained unharmed. He

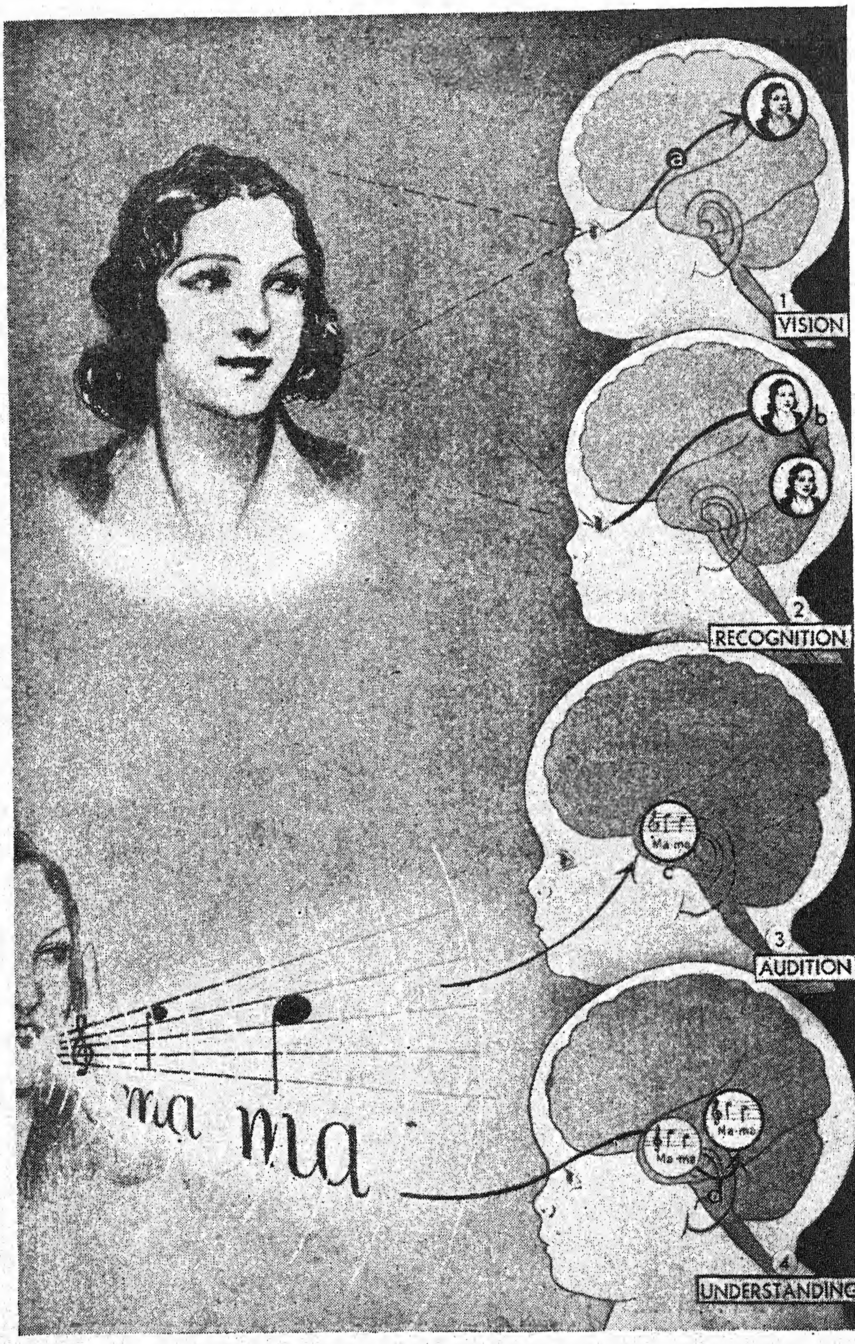


FIG. 299. *A child learns to see, recognize, hear, and understand its mother.*

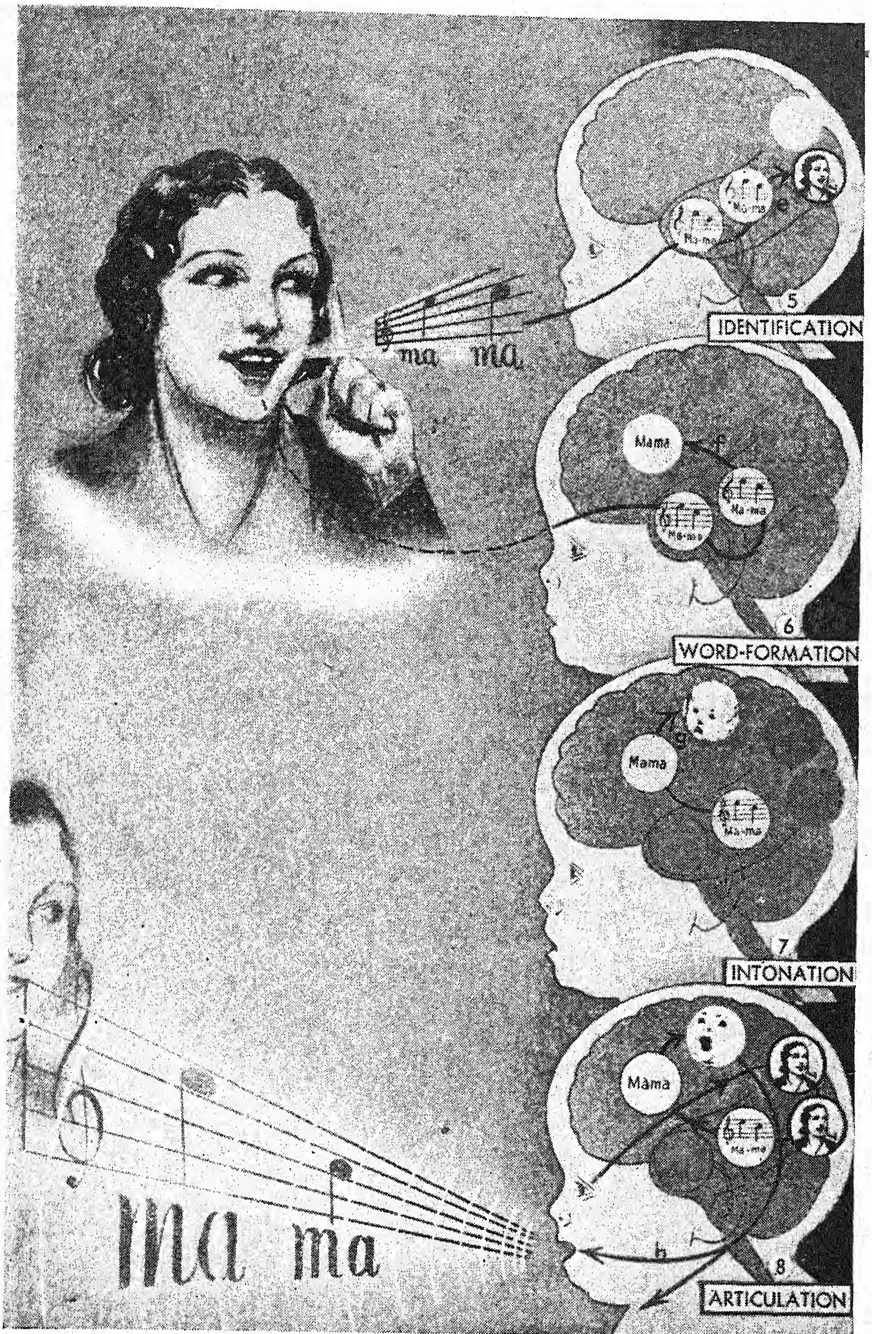
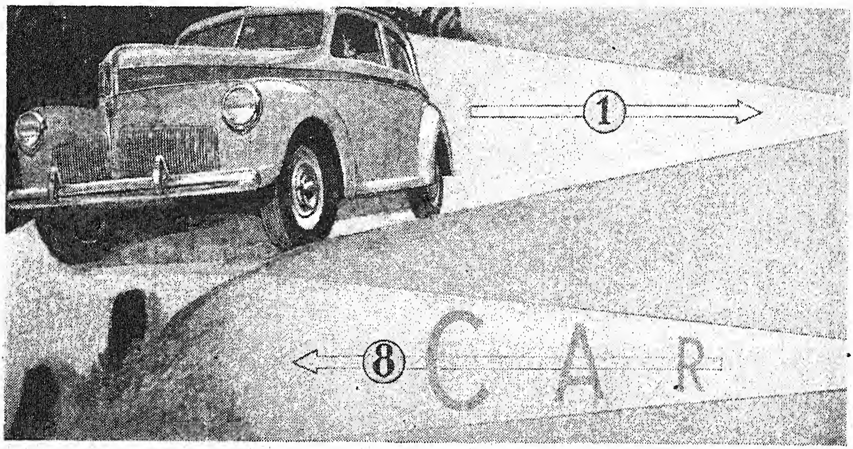


FIG. 300. *The child learns to say "Mama" at the sight of its mother.*

was still able to speak and to understand English. His wife therefore learned English and communicated with him in this second language.

Just as a person can lose part of his stock of words, he can also lose part of his memory for sounds. He may become partially deaf to high notes, while still able to perceive deep notes; or he may lose the ability to understand the spoken word, although still able to grasp melodies. A girl lost her memory centre for word sounds as a result of a brain disease. She heard the sound of words but no longer understood them. On the other hand, if songs were sung in the presence of this girl, she understood the texts because the melody section of her memory centre had been preserved.

The Language Centre. If we wish to speak a word we must first pick the sound image of this word out of the archives of our sound memories. We cannot utter a word that we don't know. Let us close our eyes and, without moving our lips, say inwardly the first sentence of Genesis: "In the beginning God created the heaven and the earth. . . ." Or, let us read slowly and silently, reading each word inwardly. This inner speaking and reading take place in a centre called the word-forming or language centre, because word-formation precedes articulate speech. It is in this centre that the stimulus is formed which we send to the motor centre of speech if we wish to say something.



The Speech Centre. The centre that activates the vocal muscles is called the speech centre. It has become famous because it was the first centre to be discovered. Because it was discovered, in 1852, by the French anthropologist Broca it is also known as Broca's centre. In contrast to the language centre, the speech centre is part of the motor area. Microscopic examination has revealed that Broca's area is not a true motor centre but only an association area—that is, a special apparatus which receives external stimuli and distributes them in suitable combination to the motor cortex, innervating the lips, tongue, vocal cords, and diaphragm. In musical terms the speech process can be described as follows: The word-

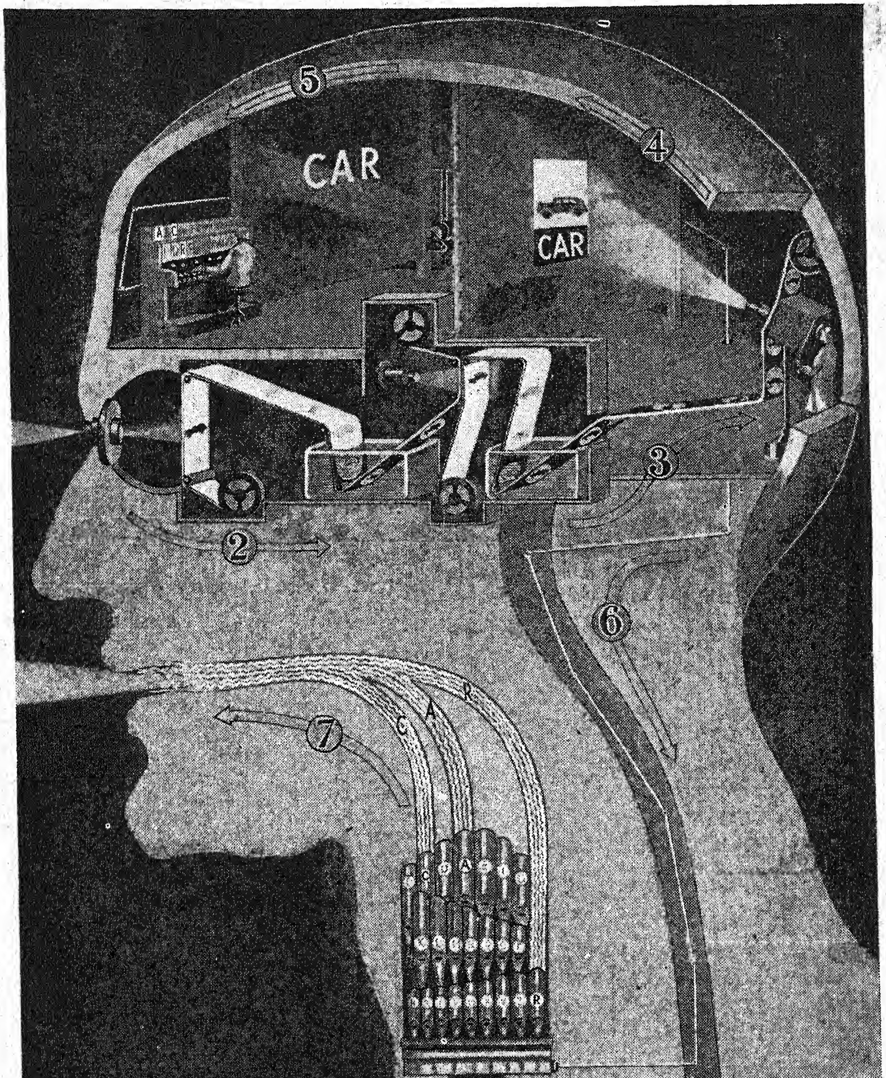


FIG. 301. *This is what takes place in the eye, brain and larynx when we see a motor car, recognize it as such, and pronounce the word "car."*

memory centre is the music file in which the sound images are kept; the language centre is the organist who wants to play and picks out a particular piece of music from his collection; the speech centre is the keyboard upon which he presses and by means of which he plays upon a certain group of organ pipes; the organ pipes are the vocal apparatus of the larynx.

A Child says "Mama" [Figures 299, 300]. At birth the cortex of an infant's brain is an unwritten

page. The sensory areas have not yet received any sense impressions. Its eyes are open, but the neurons between the eyes and the occipital lobe are not yet developed, so that the cells of the visual area receive no stimuli. After one to two months the neurons of the optic tracts (a) are ready to function, and now the infant *sees* its mother (1). As a

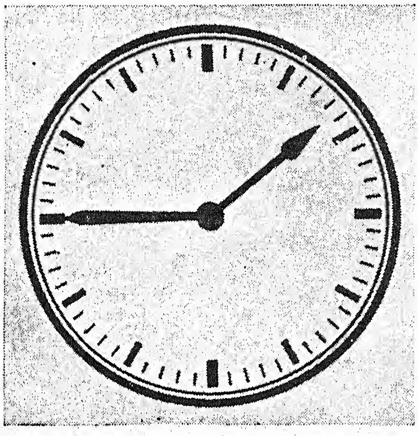


FIG. 302. *Association (I). On receiving an impression of this visual image, the brain connects it with the memory image of a clock indicating "1.45." This is association.*

result of repeatedly seeing the same objects, a visual memory centre develops near the visual centre. Here the sense impressions derived from the mother register themselves as memories. Now the child *recognizes* the mother when she approaches and smiles (2). As soon as the mother notices that the child recognizes her, she " introduces " herself by pointing to herself and saying " Mama " at the same time. At first the child hears nothing because the neurons between the ear and the temporal lobe are not yet connected. Gradually, however, the neuron (c) develops, and the child *hears* the double sound "Mama" (3). Through repetition of the stimulus a memory image of the sound of the word is produced, and now it *understands* the word " Mama " (4). The young mother is diligent in teaching her child to speak. Over and over again she repeats the word " Mama " to the child. In consequence a connecting fibre develops between the image of the mother in the visual centre and the sound of her voice (" Mama ") in the auditory centre. This is an association fibre, which connects ideas (e). When the child sees the mother it recalls not only her appearance but also the sound " Mama " (5); it *identifies* her.

Learning to Speak

Next, the mother shows the child how to shape its mouth and to expel the air. The child imitates her, and thus there arises between the auditory memory centre and the motor area a word-forming or articulation centre, the motor speech centre of the temporal lobe, in which the stimulus image for the excitation of the cells in the motor centre is prepared. The child is now in the stage of inner, unspoken *word-formation* (6). As a result of the child's repeated efforts to express the word formed within itself by stimulating the cells in the motor area, connecting fibres (g) arise and an area, an intonation centre (7), is formed within the motor area for the combined activation of the oral and laryngeal muscles. Now upon seeing the mother the child activates the vocal muscles from this centre. The stimulus which the mother provides travels by way of the centres of vision, recognition, word memory, word-formation, and muscle innervation until the child

at last *speaks* (8) and says "*Mama.*"

An Adult Says "Car." The chief activities of our intellectual life are seeing, recognizing and speaking. In reading this book we are carrying on these mental processes of seeing, recognizing, and speaking aloud or silently, for reading is nothing but a repetition of the printed words in the inner speech centre without any movement of the lips. If these three processes are united in a single picture and the component elements of these processes are represented by well-known technical parallels we can obtain a picture such as Figure 301. A photographic process takes place in the optic tract (1-4), and a musical process in the speech mechanism (5-8). The picture of the car (1) is projected on the retina, the light-sensitive plate in the back of the eye (2); it is developed in the optic thalamus and sent through the next neuron to the visual area at the posterior pole of the brain, where it is examined by the photographer (3).

Stored Images

The photographer sees it, but in order to recognize what it represents he projects it on the screen of the photographic library and sees that it corresponds to a stored memory image (4). When he has found the corresponding picture in his collection of "dark memories," it lights up as "recognition," and simultaneously in the adjoining word-memory section the name of the picture, "car," also flashes on a screen (5). In the room where the language collection is kept lives another consciousness cell, which is not a photographer but a musician. This musician sees the word "car" flash on a screen, and presses the syllable "car" on the keyboard of his organ, where the keys represent syllables. As a result of the pressure on the keys certain groups of cells in the motor centre are excited, and they in turn send the necessary action currents through the spinal cord tracts (6) to the vocal organ in

FIG. 303. *Association (II). This picture involves many more associations than does the simple clock face in Figure 302. Associative memories suggest that it represents a memorial of the First World War.*

the larynx so that it can produce the sound that aural memory associates with the image of a car (7).

What we have slowly read and traced in the picture over a period of five minutes occurs in our nervous system in a fraction of a second. During the two minutes that it takes to read a page of a book, approximately three hundred such group

images of printed words pass through our eyes to the occipital centres, and thence by way of the motor centres down to the oral muscles — an incomprehensible achievement of the double photographic-musical machine in our head. If we could watch a six-cylinder car engine running at high speed what a marvellous sight we should see! In a fraction of a second dozens of mechanical, electrical, and chemical processes, widely separated from one another, occur in a definite order; they are ingeniously co-ordinated, they stop and start automatically a dozen times a second, and when a motor-car is travelling this continues for hours and hours without interruption — a performance which astonishes us time and again! As one reads these lines, the speed, variability, and co-ordination with which the brain within the skull is working are as great as those observed in the motor-car engine

The Association Fibres. The various areas and centres of the brain are connected by neurons. The fibres of the neurons form areas in the brain which are the seat of a function which we know the brain to possess, that of association; they are known as association fibres [Fig. 305]. Look at Figure 302. We see the picture with the cells of the visual cortex. However, immediately after the arrival of this stimulus, an impulse which arises in the visual cells is carried to the neighbouring memory centre, where it tries to establish contact with our collection of memories. A connection is made with the memory image of a clock. After having found the memory image of a clock, we examine the face of the clock and determine that the longer of the hands is horizontal on the left side, while the shorter one points upwards to

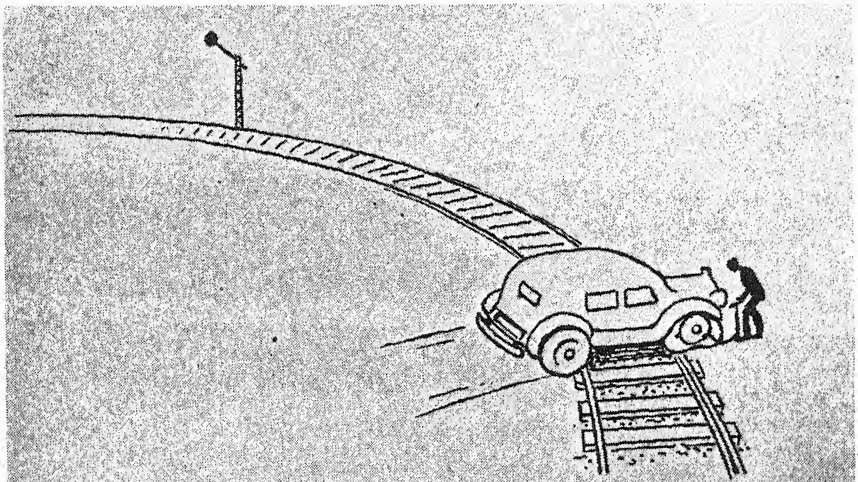


FIG. 304. *Association (III). After the two preceding elementary examples of mental association, we have here a drawing that is still childishly simple yet is sufficient to evoke a whole world of associations, memories and emotions. Already, in our imagination, we can hear the roar of the unseen train which, we feel sure, is relentlessly approaching!*

the right. In consequence we come to the conclusion that it is 1.45.

Figure 302 stimulated us to a very simple train of thought that requires but very few associative memories. Figure 303 is already more complex. We see two parallel lines that cross two other parallel lines. Below we see a trapezoid, upon which we read the numbers "1914-1918." This picture requires many more, as well as more complex, associations: the lines form a cross; the trapezoid beneath it is a plinth; "1914-1918" refers to the First World War. All these associative memories lead to the conclusion that this is a memorial in honour of those who died in that war.

Wordless Drama

Even Figure 304 is still so simple that it could be included in a children's book—yet how many dozens of associations, how many experiences and memories are necessary in order to understand it, and how many ideas and sentiments does it stimulate! Entire brain centres are excited by this motor-car driver who is acting contrary to all the rules that regulate motor-vehicle traffic. In our imagination we can already see and hear the approaching express train, and, depending on the manner in which we associate things, we can construct an entire picture of the approaching catastrophe.

The Association Areas. The association fibres consist of short ones that connect the cells within a particular area [Fig. 305], and long fibres between different areas. The main bundles of association fibres connect the frontal, temporal, and occipital lobes, and we speak of anterior, central, and posterior associational areas. Abstract processes of thought, concept - formation, and subjective associations are supposed to be located in the frontal lobe. Here lives the reflective part of the personality; it is the dwelling-place of the philosopher. The central associational area of the temporal lobe is the seat of all the connections that are made through the

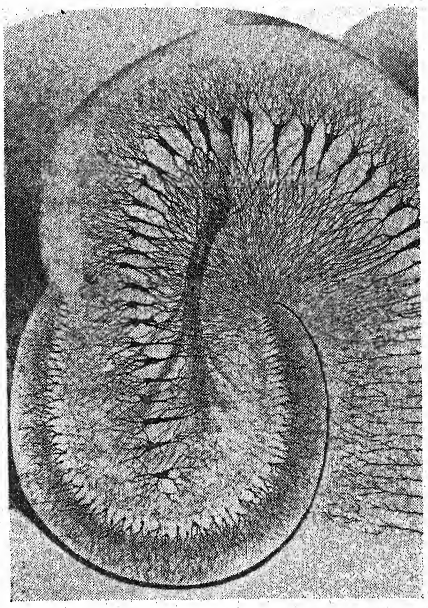


FIG. 305. *The apparatus with which we carry out thought processes. Among the dark cortical cells is seen a perpendicular sheaf of association fibres which form local connections between the feeling and the thinking cells. Similarly, the frontal, temporal and occipital lobes are all connected by longer association fibres.*

agency of the centres of word- and sound-formation which are located there—that is, all musical and speech processes. Here live the orator, the musician, and the person with a talent for languages. The posterior associational area takes care of visual impressions. With the help of this area we recognize and

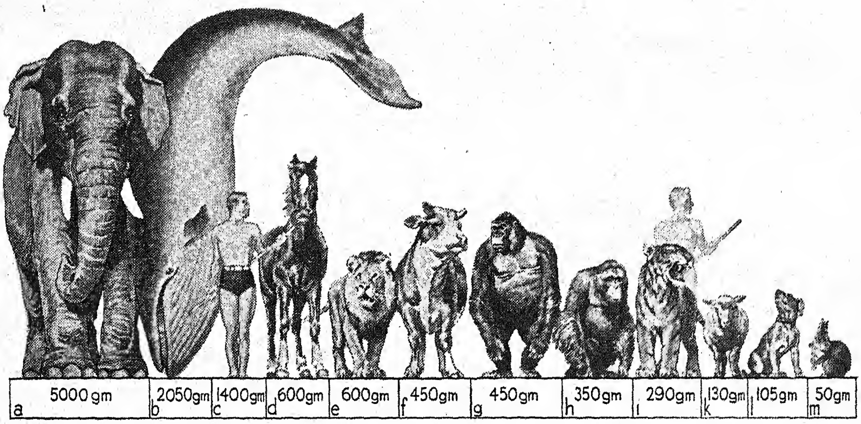


FIG. 306. *The absolute weight of the brain. Although the brain of man (weighing 1,400 gm.) is far from being the largest of animal brains, yet in a series of brain weights it takes its place among those of much larger animals (c). If man were grouped according to the weight of his body, he would have to be placed at (i).*

comprehend the world. Here the connections between the individual and his environment are established, and from this area arise the pictures of imagination and dream life. The associational areas are developed to a varying degree in different people. Each of us appears to prefer one particular type of association, so that in general three types of human beings may be distinguished on this basis: a visual type of person, who grasps most easily that which is seen; an auditory type who is most receptive to acoustic stimuli; and a type of person who is inclined to abstract thinking and a consideration of objects of thought from a conceptual point of view.

The Absolute Weight of the Brain. The human brain weighs about 1,500 grammes ($3\frac{1}{3}$ pounds). Man does not possess the largest brain among living creatures, since the brain is not only the organ of mind, but primarily and originally a reflex apparatus for sensory perception and muscular movement. On this account large animals have large brains to supply the needs of their large bodies. The brain of a big whale is six times as large as a human brain, and that of an elephant is three times as large [Fig. 306]. Man occupies third place, although according to his size he should not be occupying a place between a rather small whale and a horse, but should be standing where the shaded human figure has been placed, between the tiger and the sheep.

The Relative Weight of the Brain. The relative weight of the brain is the relation between the weight of the brain and that of the body [Fig. 307]. The smaller an organism, the greater is its relative brain weight. In the canary the weight of the brain amounts to $\frac{1}{12}$ of its total weight, while in a whale it amounts to $\frac{1}{4000}$ of the total. A newborn human being has the greatest relative brain weight ($\frac{1}{7}$) of all creatures. Compared with that of an equally heavy domestic animal, the weight of the

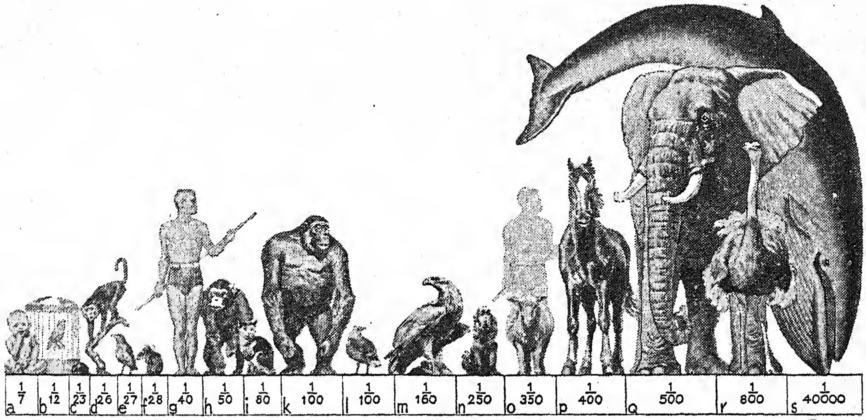


FIG. 307. *The relative weight of the brain. In proportion to the weight of the body, small animals have heavier brains than large animals. The relatively heaviest brains are those of songbirds (b) among warm-blooded creatures, and, among mammals only, those of mice (f). According to its body-weight, a newborn child ought to have a brain as heavy as that of a dog (n)—that is,* $\frac{1}{250}$ *of its body-weight; yet of all warm-blooded creatures its brain has relatively the greatest weight—*$\frac{1}{7}$ *of the body-weight (a). Again, the brain of an adult human might be expected to have a weight of approximately* $\frac{1}{351}$ *of that of his body (o). Actually, the proportion is much greater, being nearly* $\frac{1}{40}$ *(g).*

human brain should only amount to $\frac{1}{350}$ of the body weight (see shaded human figure), but actually the weight of an adult human brain amounts to $\frac{1}{40}$ of the body weight. Thus man does not head the list as regards either his absolute or his relative brain weight, but in both cases he occupies a very favourable place.

The Development of the Brain in the Course of History. As the animal series clearly shows, the development of the brain began among the apes. The position of the ape is likewise more favourable than might be expected. Characteristic and at the same time decisive for man is not the fact that the brain has increased in size, but rather that it has been transformed and has developed the frontal lobe, as evidenced by Figure 292. If one superimposes the skull profiles of an ape, of the prehistoric man of Java (Pithecanthropus—1,000,000 years old), of the Ice Age man of Europe (100,000 years old), the extant Australian blackfellow, and the modern European, one recognizes that while the size of the brain has not changed greatly during the past 100,000 years, its form has changed very much. The brain has pushed forward so that modern man surpasses his ancestors not so much by the greater size of his brain as in the possession of the frontal lobes [Fig. 308]. The forehead makes the man!

Brain and Race. Most of the statements in the literature concerning differences in the size of the skull and the weight of the brain among various races and peoples are of little value. From a technical point of view the study of the brain is one of the most difficult fields of quantitative biology. Most of the measure-

ments of the skulls and brains of primitive peoples have been made by travellers or expeditions. Often the investigators had no specialized training and the investigations were almost always carried out in haste and without the necessary preparation. Different investigators used different instruments, chemicals, and methods, and, even more important,

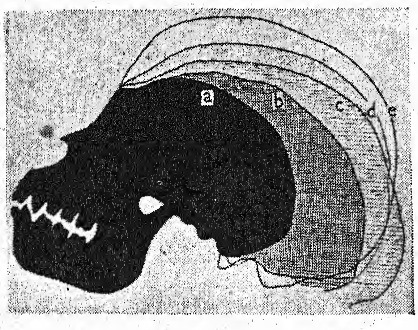


FIG. 308. *The skull profiles of (a) an ape, (b) the prehistoric man of Java, (c) a Stone Age man, (d) an Australian blackfellow, and (e) a modern European. During recent ages, the human skull has not grown much larger, but it has become more prominent across the brow, as the frontal lobes of the brain have developed.*

the studies were made upon completely uncontrolled samples of human material that the investigator obtained by chance during his journey. If one examines these studies carefully, one finds that opinions regarding entire peoples were often expressed on the basis of a dozen rapidly performed investigations. Yet even a mass investigation of brains carried out by specialists in an African Negro village, either in a dry desert climate or in a hot humid tropical forest, may lead to results that differ greatly from each other and deviate sharply from results obtained by means of identical methods on equivalent human materials in Europe. The brain consists of 70 per cent water; that is, it contains more than $2\frac{1}{4}$ pounds of water. This fact indicates the wide margin of error to which such studies are subject, due to the varying moisture content of the brains at the time of investigation.

Apart from the material sources of error involved, one must view all statistical studies of this kind with the greatest distrust. Even in Europe the figures obtained by different investigators for the simplest weight determinations differ greatly.

The apparently very remarkable fact that these investigators always obtain higher values for their own countrymen than for other nationalities seems to indicate the operation in these cases of a personal factor similar to the "personal equation" of the astronomers. For this reason little trust can be placed in most existing statistical studies of brains and skulls. Instruments and methods established and adopted by international agreement must be introduced for such measurements, and only the results of such investigations should be accepted as are carried out by recognized investigators under specified conditions on sufficiently large samples and are confirmed by scientists of other nations on the basis of independent control studies. Only then will it be possible to replace the worthless, tendentious, pseudoscientific literature of the present by scientifically valid materials upon which judgments may be based.

As we have already seen, in human biology the results obtained in man are quite often very different from those we expect and it may be so in this case. This much seems certain at present: neither the size of the

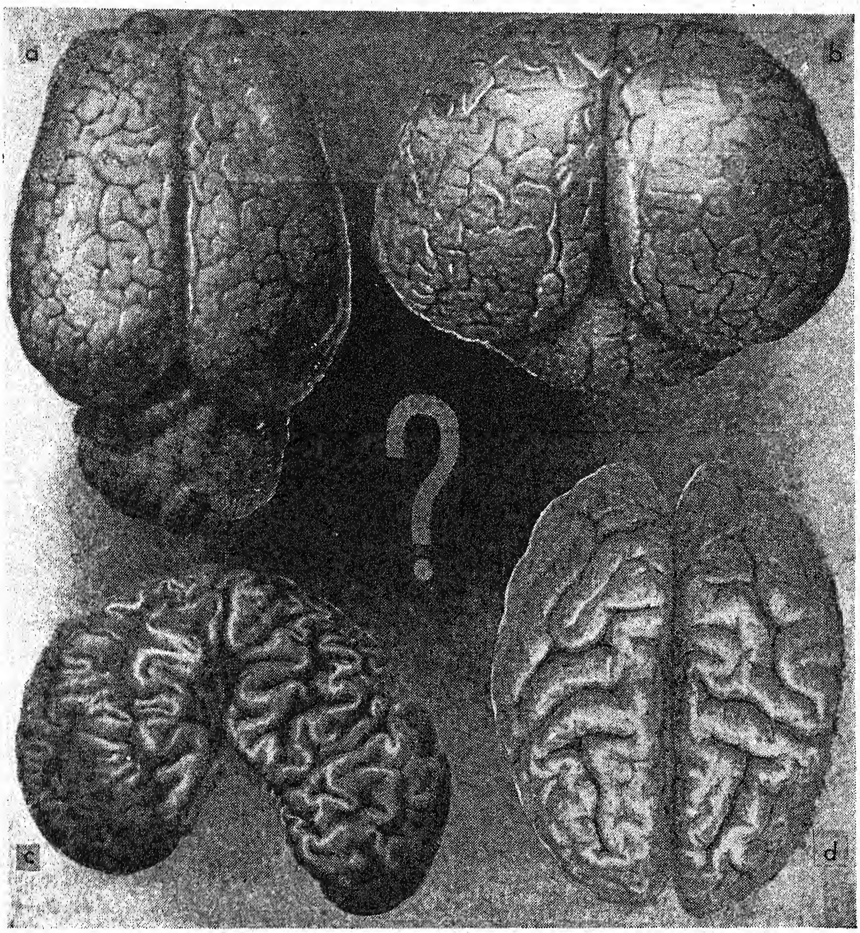


FIG. 309. *The supposition that the human brain surpases all others in the number and development of its convolutions is a fallacy. Here, arranged side by side for comparison, are the brains of (a) a horse; (b) a dolphin; (c) an elephant; (d) man.*

skull nor the weight of the brain is in any direct relationship to intellectual achievement. The so-called primitive races have by no means the smallest skulls and the lightest brains; instead we seem to find a very diverse distribution of both skull size and brain size. Kaffirs have larger heads than Scots, and the Eskimos have larger brains than the countrymen of Huygens and Rembrandt! With regard to the weight of the brain, Europeans are closer to Negroes than to the Chinese, who have the largest brains of all the races. Furthermore, the brain with the most extensive cerebral cortex and the most finely modelled appearance is that of—the Hottentot!

Brain and Education. At the beginning of the present century the scientist Möbius compared the head

sizes of 100 educated persons with those found among 100 mentally deficient convicts, and arrived at the following result: the majority of the educated persons as well as of the convicts had average-sized heads. More convicts (10 per cent) and fewer educated persons (1 per cent) were found to have heads smaller than the average, while more educated individuals (40 per cent) and fewer criminals (3 per cent) had larger heads than the average.

Large Brains and Small

Thus is obtained a result typical of all such investigations; 100 educated persons as a group have larger skull and brain measurements than 100 criminals. In individual cases, however, no relation can be established. There are educated people with small heads, and criminals with large ones. A small brain may be very valuable and a large one good for nothing.

Brain and Talent. One arrives at the same result when the brains of productive individuals are compared. There is no direct relationship between the size of the brain and talent. Most talented individuals have a brain of average size; a relatively large group have larger brains and relatively few have smaller ones. Nevertheless, the heads of three of the greatest geniuses in three different fields of activity, Raphael, Dante, and Bach, were smaller than the average.

Exceptional Brains

The largest brain investigated until now (2,222 grammes or 4 lb. 14½ oz.) belonged to an ordinary working man. The two largest brains of talented persons were those of the French lawyer Bouny, who had an extraordinary memory, and of the Japanese anatomist Taguchi.

The Convolutions of the Brain. After the various methods of studying the brain based upon measurement had been found to be deficient, it was hoped that better results might be obtained by studying the individual convolutions. In this field, too, however, a number of premature conclusions were reached, which upon critical re-examination proved to be incorrect. The first of these false conclusions, which is still to be found in a great many books, was that the human brain has the most finely developed convolutions. The brains of four mammals are shown in Figure 309: (a) horse, (b) dolphin, (c) elephant, (d) man. Which of these brains has the most beautiful convolutions? It is difficult to decide. Yet one thing can be said: the brain with the coarsest and simplest convolutions is that of man!

Retrogression

An abundance of cerebral convolutions is not an index of intelligence, as one usually hears, but simply the result of a lack of space. If a brain has not sufficient room to expand, its surface buckles and develops convolutions in order to accommodate itself to the restricted space. The dolphin has a brain with numerous convolutions because it is a pirate and has developed its skull as a weapon, so that the brain is forced to occupy a more restricted space. Here the many convolutions are an expression of retrogression. That is biology!

Therefore the widespread idea that the numerous convolutions of the human brain are related to mental ability is to be accepted only with

great caution. Like all these ideas, it also contains a grain of truth, a general truth, which is only generally true, however, and cannot be applied to individual cases. In Figure 310 twelve brains are arranged according to their weights. At the bottom is the brain of an orang-outang and above one of the smallest human brains yet found. It belongs to a female idiot. Nevertheless, idiots do not invariably have small brains, but often very large ones.

Out-size Brains

Like normal persons, idiots have small, average-sized, or large brains —no general law can be found. At the upper end of the series is the heaviest human brain that has yet been measured. It was also obtained from an idiot, an individual who was a mental defective because the connective tissue in his brain had proliferated to such an extent that the nerve cells could not develop. It has fewer convolutions, yet the large brains of normal individuals shown below it, with many convolutions and weighing 1,600 to 2,000 grammes ($3\frac{1}{2}$ to $4\frac{1}{2}$ lb.), belonged to ordinary people.

In the centre of the illustration one sees the brain of an outstanding man of the nineteenth century, the historian Mommsen. There is no doubt that the convolutions of this brain are exceedingly well developed. Yet one should not be misled by these appearances. Mommsen was almost ninety years old when he died, and the brains of old people, because they have shrunk, appear to have more convolutions than the brains of young people. On the other hand, investigations of the brains of other famous persons establish the fact that they were

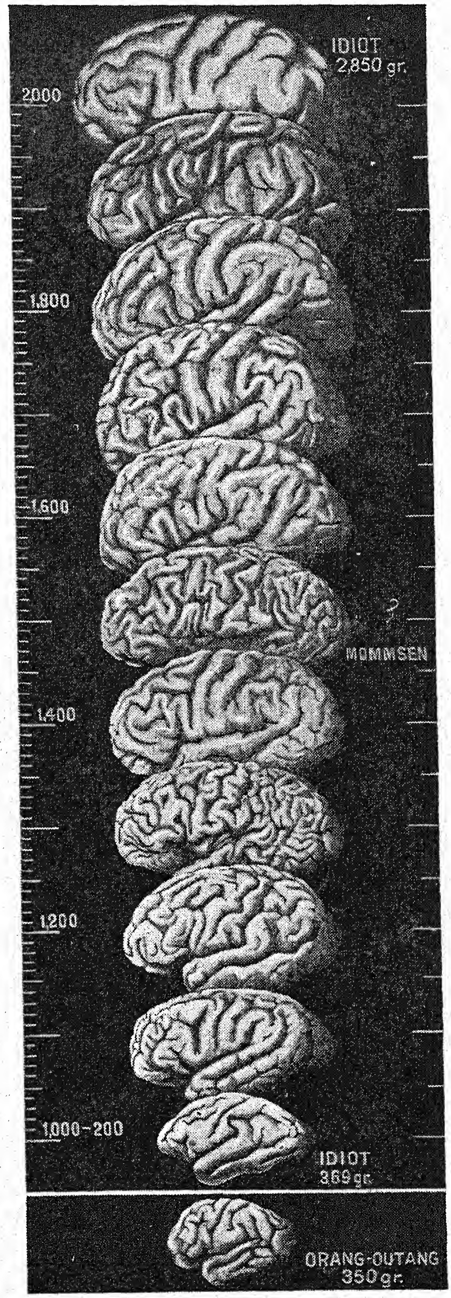


FIG. 310. *Comparative weights of selected brains: above the line are human brains.*

by no means characterized by an abundance of convolutions. In isolated instances remarkable deviations were found. The temporal lobe of the brain of Hans von Bülow, the famous musician of the Wagner period, and the first husband of Cosima Wagner, had so many convolutions that it was impossible to record them in the usual manner. The talented orator Gambetta had two speech convolutions instead of one, and in the brain of the brilliant Hungarian orator Szilagyi the speech convolution was 37 millimetres wide instead of 23! However, when the brain of the language genius Sauerwein, who wrote poetry in more than fifty languages, was investigated because it was hoped that it would reveal interesting scientific discoveries, nothing striking was discovered despite very thorough study. The brain of Helmholtz, who was a true mental giant, exhibited nothing remarkable except for a slight deviation, on the basis of which attempts were made to explain his talents. Later the same deviation was discovered in a chimpanzee.

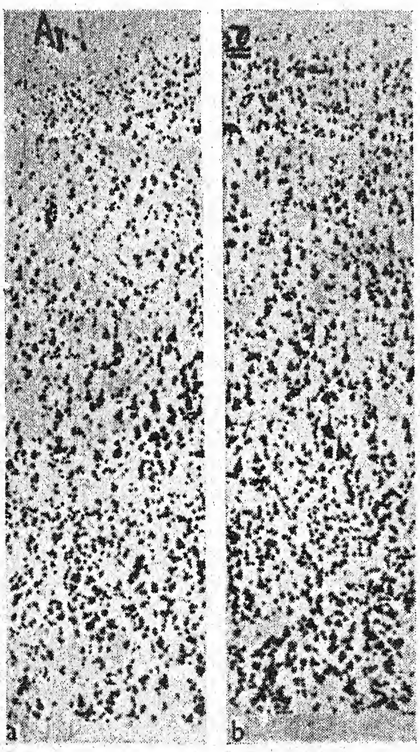


FIG. 311. *Sections of the first human brains to be subjected to precise and exhaustive investigation. They are from the brains of (a) a Russian peasant, (b) Lenin. Lenin's cerebral cortex has 25 per cent more cells and association fibres than (a).*

Cell Counts. After the failure of the nineteenth-century methods, science began to pursue new paths. Under Czarist rule, Russia already had the most famous institute for brain research, with scientists of international reputation. In the spirit of these traditions a special institute was established after Lenin's death for the study of his brain; and the best-known specialist in this field was called from Berlin to conduct the investigation.

Lenin's Brain

By means of apparatuses specially constructed for the purpose the brain was cut according to a predetermined plan into more than 30,000 sections, each having a thickness of $\frac{1}{100}$ millimetre and over a period of years the cells in the various layers were counted, like the stars in stellar photographs. For control purposes the brain of an average Russian was studied in a similar manner, and it was found that the cells in Lenin's brain formed denser clusters, and that the cells and the association fibres were more numerous [Fig. 311]. With investigations of this type science has set foot upon a new and promising

path, but the possibilities of this new approach will not be achieved until ten thousand brains of individuals famous for their accomplishments have been subjected to minute and precise investigation, instead of the mere ten that have been studied in this way until now.

Brain Weight in the Sexes

Sex and Brain. If one compares a male brain with a female brain (using modern methods), one cannot say which belonged to a man and which to a woman. However, if 100 male brains are weighed, an average weight of 1,450 grammes is obtained, while the average weight of 100 female brains is only 1,250 grammes. This difference in weight is striking and is not due alone to the fact that the female body is smaller than that of the male. The differences are already considerable at birth and can be explained only by the fundamentally different biological position of man and woman. In other words, the lesser weight of the female brain is a secondary sex characteristic.

The Sleep Centre. Sleep, which is so important for the restoration of the fatigued organs and tissues of the body, has been the subject of considerable study, yet a completely satisfactory explanation of sleep is still lacking. It appears probable, however, that the sleeping and waking of the body are regulated by a complex centre in the depths of the brain, which is known as the sleep centre. This centre is regulated by the blood. Neuromuscular excitation is accompanied by chemical processes, in the course of which acetylcholine, as well as other substances, including calcium, are liberated at the ends of the nerves, especially at the neuromuscular junction. In the course of a day calcium passes into the blood and stimulates the sleep centre. If calcium is injected directly into the sleep centre, the animal falls asleep immediately. However, if calcium is injected into the blood-stream, fatigue and sleepiness do not appear, since the sleep centre must first be "sensitized" by special fatigue substances such as lactic acid before it will react to the calcium.

Sleepy Sickness. Our knowledge of the sleep centre is due in large measure to a disease known as epidemic encephalitis or encephalitis lethargica. This disease attacks the brain stem and may produce either sleeplessness or somnolescence. If the pathological process advances antero-posteriorly, the sleep centre is injured first, and the patient can no longer sleep. If the disease process stops at this point, the affected individual will be troubled by insomnia for weeks and even months. On the other hand, if the process creeps from the posterior part of the brain stem anteriorly, the waking centre is the first to be put out of order and the individual is no longer able to wake up. He sleeps for weeks and even months. Such are the cases that are reported in the newspapers. "A young girl has been sleeping without interruption for nine years. . . ."

Brain Sleep and Body Sleep

Rigidity of the Body and Somnambulism. The sleep centre blocks, on the one hand, the cerebral cortex, so that the individual's volition and consciousness are abolished (brain sleep), and on the other the ganglia of the brain stem, so that the internal organs and limbs fall asleep;

for example, the muscles lose their tonus (body sleep). Normally both reactions are connected, but under certain conditions they may be separated. If a chicken's head is pressed against the ground and a line is drawn with chalk right in front of its eyes, it fixes its attention on the line and cannot move because the centre which controls the position of the eyes is closely connected with the sleep centre and certain positions of the eyes interrupt the function of the motor fibres of the pyramidal tract, thus producing temporary paralysis.

Hypnosis

The hypnotist accomplishes something very similar. By concentrating the subject's attention on some single stimulus, such as a point of light or perhaps the hypnotist's finger, thus reducing the scope of orientation of the subject in his surroundings, the latter is placed in a state favourable for the onset of sleep. This effect may be enhanced by holding the finger very close to the eyes of the subject until fatigue of the eye muscles ensues as a result of the concentrated effort which is made to maintain ocular convergence. When this occurs the operator suggests that the subject's eyes are closing in sleep. Conversely the cerebral cortex can sleep while the body is awake. An excessively tired soldier may fall asleep while marching; his brain sleeps, that is, but his legs continue to march along with the column of soldiers. In the case of individuals with abnormal modes of reaction of the nervous system, brain and body sleep may sometimes become disassociated; such people get out of bed while still asleep and walk about (somnambulism). The cerebral cortex continues to sleep while the body is awake. Genuine sleep-walkers are observed very rarely. Shakespeare lets the murderess, Lady Macbeth, who is being tormented by pangs of conscience, appear as a sleep-walker. Extremely impressive is the separation of body and brain sleep in hypnosis, where either type of sleep can be turned on or off at will as in a machine, thus enabling the hypnotist to achieve the remarkable phenomena of the hypnotic state.

How Much Sleep Does a Person Need? Actually, just as with most other questions dealing with modes of living, there is no generally valid answer. Every person should sleep as long as he needs in order to feel happy and be able to work in the best possible manner upon awaking. How one sleeps is not so important as how one awakes. In judging a person's life, we don't ask how long he slept, but how he lived and what he accomplished during his waking hours. History records many instances of famous persons who could be active day and night with only the shortest spells of sleep—sometimes little more than a nap in their chairs.

Long Sleepers

In contrast to these "short" sleepers, history records almost similar numbers of "long" sleepers whose achievements have made them equally famous. Goethe and Schopenhauer were long sleepers, and the philosopher Kant was such an unnaturally long sleeper that his servant received instructions to awake him after he had slept seven hours, and despite any protest, to remove him forcibly from bed. The explanation of the restful effect of

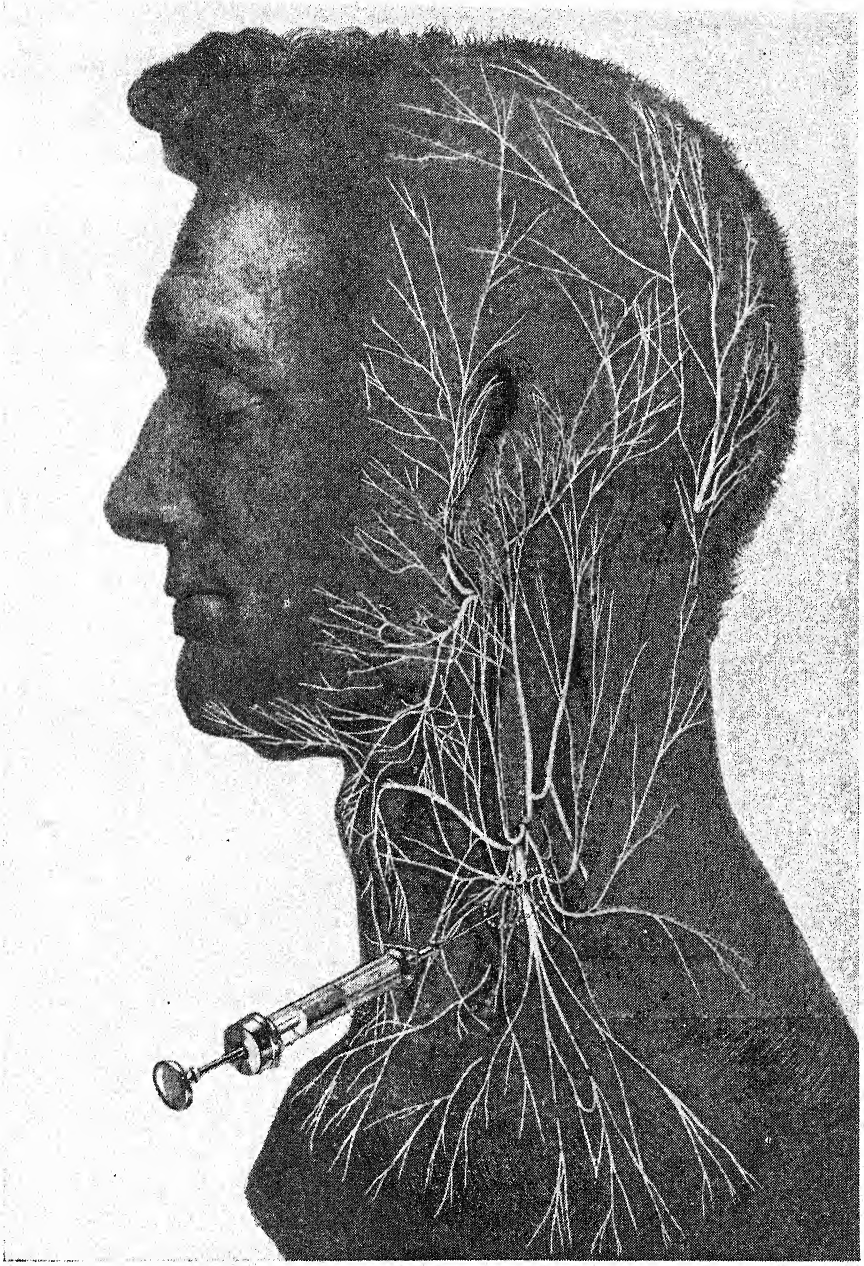


FIG. 312. *Block anæsthesia. In this form of anæsthesia the nerves are rendered insensitive by injecting cocaine around them at the point of origin. In this way the area supplied by the nerve is anæsthetized for about an hour.*

a short sleep is the fact that it is a deep sleep. During the night before the Battle of Gaugamela, Alexander remained awake longer than anyone else. Then, wrapped in a cloak like his soldiers, he lay down on the earth. He slept so deeply that he did not hear the noise of the army preparing for battle. His general Parmenio had to wake him three times to give the command to attack.

Insomnia. Just as there are different types of sleep, there are also different types of sleeplessness: delay in falling asleep, shallow sleep, and premature awakening. A person may sleep eight hours, but his sleep may be so shallow that despite a sufficiently long sleeping period he may still not have had enough sleep. In order to treat insomnia rationally, the type of sleeplessness and its cause must first be determined. It is senseless to take a hypnotic that acts slowly and has a prolonged effect, if the person in question is simply unable to fall asleep but sleeps very well after having fallen asleep. On the other hand, a hypnotic which does not produce a prolonged effect is of little value when a person suffers from premature awakening. Above all, the cause of the sleep disturbance must be recognized. Frequently insomnia is due only to an error in the technique of going to sleep, and consequently requires no

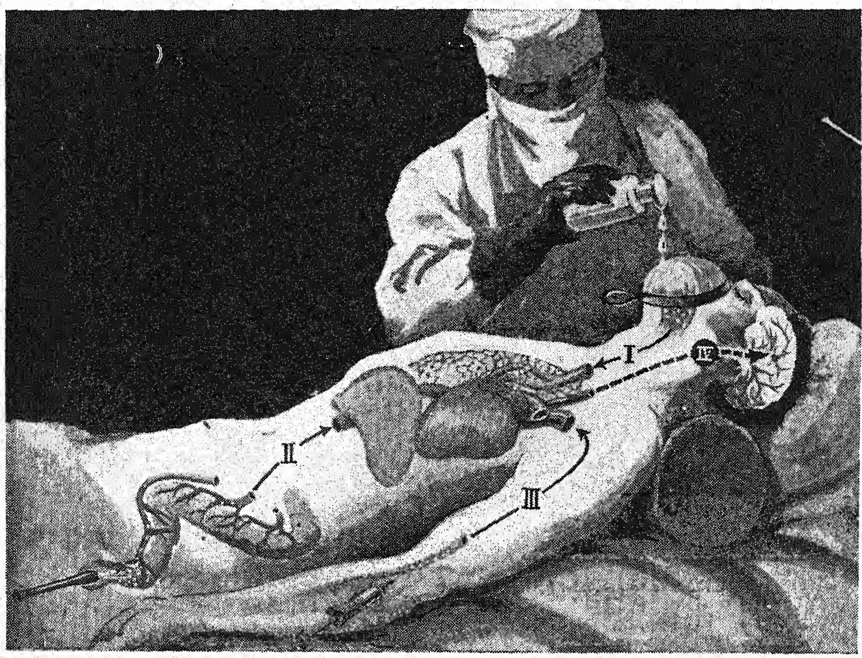


FIG. 313. *Complete, or general, anæsthesia. Narcosis of the brain (IV) may be achieved in one of three ways. Inhalation anæsthesia (I) follows the sequence: inhaled air (containing a volatile anæsthetic)—trachea—lungs—blood—brain. Rectal anæsthesia (II) proceeds thus: enema—rectal vessels—liver—blood—brain. Injection anæsthesia (III) takes the direct path: vein—blood—brain.*

hypnotic, but rather enlightenment and education. The aim of a rational treatment of insomnia is to see that the patient obtains his natural amount of sleep without the aid of hypnotics.

Anæsthesia. Anæsthesia is one of the greatest achievements in the history of medicine—indeed, in the entire history of human progress. The benefit which anæsthesia brought to mankind, and the impulse which it furnished for the development of medicine and research, can hardly be expressed in words.

Inhalation

The "classic" form of anæsthesia is inhalation anæsthesia. A mask placed over the mouth is saturated with a volatile narcotic, such as chloroform or ether [Fig. 313 (I)]. The inhaled substance passes through the lungs into the blood and narcotizes the brain (IV). Inhalation anæsthesia, which is still the most commonly used type at present, has the great advantage that it can be regulated. Depending on the needs of the operation, the anæsthesia can be kept light or deepened, it can be extended over a long period of time or interrupted. It has the disadvantage that it is unpleasant for the patient. However, this need not be the case if the patient has been adequately prepared by means of appropriate sedatives, and above all if the administration of the anæsthetic is in the hands of a trained anæsthetist.

Injection

During recent years volatile anæsthetics have to some extent been replaced by hypnotics that are not inhaled but which are administered to the body by means of an enema (II) or by injection into the bloodstream (III). These newer methods still have some drawbacks, yet it is probable that they will be used more and more as these unpleasant features are removed. Characteristic of all forms of general anæsthesia is the fact that the anæsthetic reaches the brain by way of the blood and paralyses consciousness.

Local Anæsthesia. Approximately at the same time that the power of ether and nitrous oxide to induce anæsthesia was being discovered in America, an Englishman named Wood invented an instrument which is as simple as it is ingenious. This is the hollow needle or canula, which has been little appreciated, but which has probably become as important for mankind as anæsthesia, the incandescent lamp, or the aeroplane, since by means of such needles medicaments are injected into the body [Fig. 312].

One can estimate that from one to two million people are saved from a premature death annually by the use of Wood's needle, by means of which it is possible to introduce medicaments rapidly into the bloodstream without any damage or dilution by the digestive juices. Numerous important therapeutic methods such as serotherapy—that is, the injection of antitoxins and vaccines against diphtheria, typhoid, cholera, etc.—Salvarsan treatment of syphilis, insulin therapy of diabetes, technically complicated dental operations, and, above all, the entire experimental technique in the laboratory for the trial of medicaments rest upon the possibility of introducing substances into the body by means of Wood's hollow needle.

Local anæsthesia is a general term comprising a number of methods by

means of which the operative area itself, and not the brain, is rendered insensitive by anæsthetizing the nerve endings or the nerve tracts.

Cocaine Swab. The oldest and simplest method, which is still used today, is to swab the mucous membranes with cocaine. It deadens the ends of the nerves, so that the painted area can be treated without producing any sensation of pain.

How Cold Deadens Pain

Freezing. It is well known that when the fingers or the ears become cold in frosty weather, they become insensitive. Intense cooling renders the nerves unable to conduct sensory stimuli. This experience is utilized in anæsthetizing smaller skin areas. Ethyl chloride, a rapidly volatilizing substance, is sprayed on the area to be anæsthetized. In consequence of the evaporation of the ethyl chloride the area cools off rapidly and becomes insensitive, so that minor operations which do not take much time may be carried out painlessly.

The injection of cocaine solutions into the tissues has become more important than these two surface methods. If some adrenalin is added to the cocaine so that the injected solution is not removed rapidly by the blood but remains in the tissues for some time, the injected area remains anæsthetized for approximately an hour. It is not necessary to saturate the entire area in which one wishes to operate, but simply to inject the solution at the boundaries of the area so that the nerves are unable to conduct any impulses and the surgeon can operate painlessly in the anæsthetized space [Fig. 314 (I)].

Block Anæsthesia. Arms and legs are rendered insensitive by injecting the anæsthetic solution around the chief sensory nerves in the shoulder or hip region. The nerve loses its conductivity after being infiltrated with cocaine, so that the entire area which it supplies beyond the point of injection becomes insensitive. A person whose arm nerves have been cocainized in the shoulder region has a feeling that his arm has been taken away from his body, and he must convince himself by looking at it and touching it that he still has his arm (II). Naturally, besides the arms and legs, any other region of the body can be anæsthetized by means of block anæsthesia if one infiltrates cocaine into the nerves supplying the area, as shown in Fig. 312.

Spinal Anæsthesia. The spinal cord is the largest of all nerve trunks. A canula is introduced into the spinal canal, where the spinal cord is suspended, and a cocaine solution is injected. In consequence all the tracts of the spinal cord are anæsthetized [Fig. 314 (III)]. The patient feels as if his body ceases to exist at the level of the injection.

Modern Miracles

Injecting the spinal cord to cause anæsthesia is no greater miracle than the other forms of anæsthesia. If the two greatest physicians of antiquity, Hippocrates and Galen, were to witness a modern operation and see how a person who had just been walking and talking is asleep ten minutes later, how his abdomen is opened, and how this person upon awakening later in his bed remembers nothing of what happened to him—if they were to see this, their astonishment would be boundless and in accordance with ancient usage they would declare these phy-

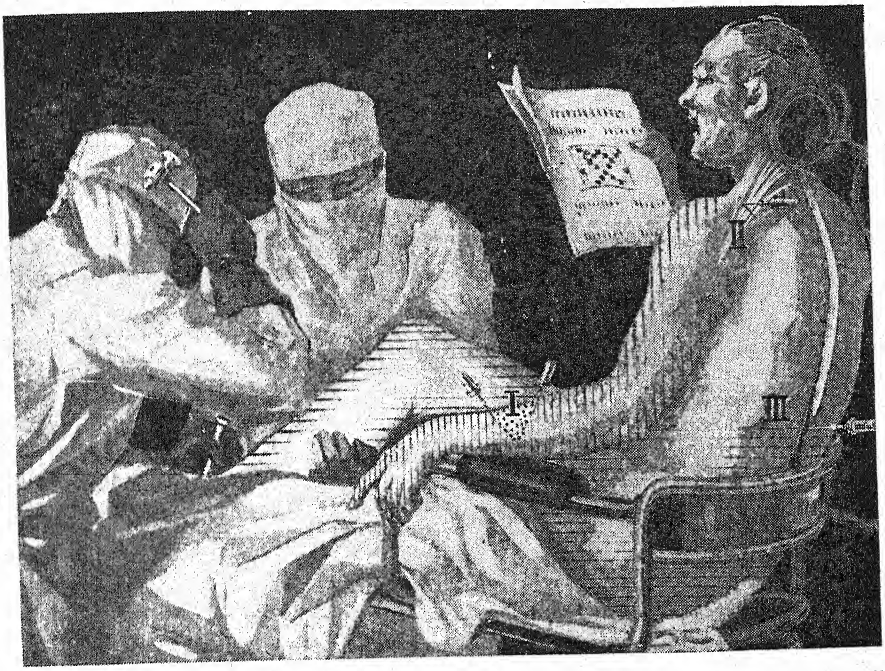
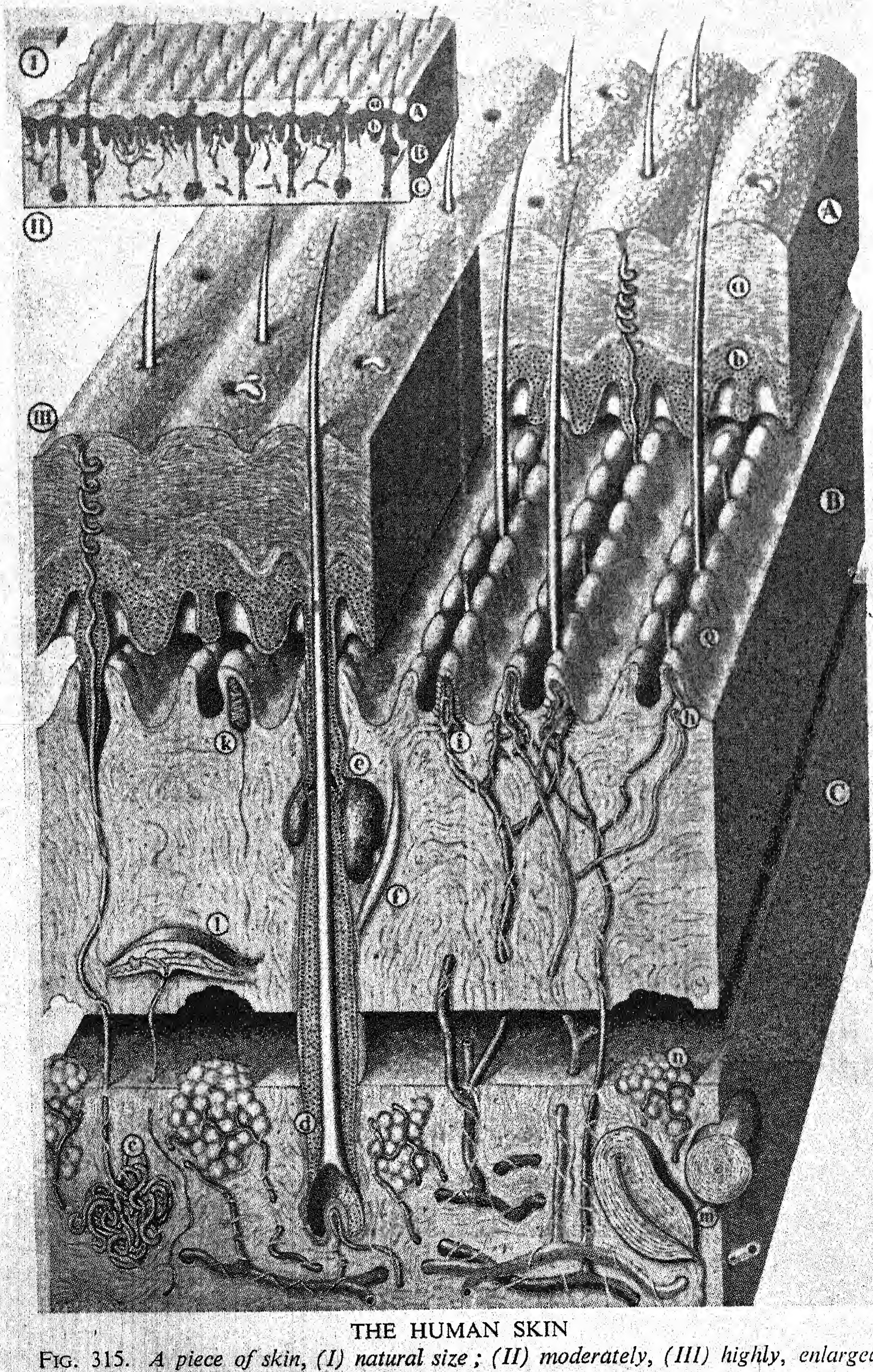


FIG. 314. *Partial, or local, anæsthesia. (I) The injection of cocaine round a small area, so as to render it insensitive for operation. The insensitive area is shown dotted. (II) Block anæsthesia, or injection of the anæsthetic around a main nerve trunk in order to anæsthetize an entire limb. The insensitive area is denoted by vertical lines. (III) Spinal anæsthesia; injection of an anæsthetic into the dural sac of the spinal cord, by which the entire lower part of the body is deprived of feeling. Horizontal lines indicate the insensitive area. As a result of spinal anæsthesia, it is possible for the patient to read in tranquillity while a severe operation is performed upon his leg.*

sicians worthy of divine honours. Spinal anæsthesia, however, demonstrates this miracle in a more dramatic and striking manner than any other form of anæsthesia. We see a man sitting in a semi-inclined chair. The surgeon has given him a newspaper so that he will be occupied; and while the patient is reading the paper a growth is removed from his leg, yet he feels nothing, not the slightest pain. But wait, he does notice something. His voice is heard suddenly from behind the newspaper. "I cannot read; someone is knocking against the chair down there." He is right. Someone is knocking, but not against the chair. The surgeon is chiselling the tumour out of the patient's ankle. Naturally this disturbs the reader. . . . Such is present-day anæsthesia.



THE HUMAN SKIN

FIG. 315. *A piece of skin, (I) natural size; (II) moderately, (III) highly, enlarged.*

IX: THE SKIN AND THE SENSORY ORGANS

CHAPTER XXXVI

The Skin

THE MOST DIVERSIFIED ORGAN. HUMAN LEATHER. FINGERPRINTS. THE ETERNALLY YOUTHFUL SKIN. THE HAIR. THE FATTY SKIN CREAM. SWEAT. THE ACID COAT. MASSAGE OF THE SKIN. BATHING. SUN-BATHS. HOLIDAY RULES. LIGHT AT PRESENT AND IN THE FUTURE.

ANYONE considering the human body is tempted to observe of each organ in turn: "*This* is the most wonderful of all the organs." However, one soon recalls what one has previously learned concerning other organs: the fantastic structure of the bones with the bone-marrow which produces several hundred million blood cells every second; the beating heart, which for seventy years sucks in and expels one-sixth of a quart of blood every second; the liver within a thimbleful of whose substance are carried on as many chemical processes as in a factory; the brain with its millions of telephone connexions and mysterious functions of consciousness—truly it is impossible to give preference to any organ of the body.

A Wonderful Organ

The human skin is likewise an organ the sight of which tempts one to bestow the grand prize upon it. What a profusion of organic structures in such a narrow space! What a profusion of networks, cables, antennæ, switches of tissues, glands, blood vessel loops, alarm mechanisms, and how many invisible chemical and physical mysteries which our instruments have as yet been unable to elucidate!

The skin is one of the largest organs in the body. The other organs are compact and take up as little space as possible. The skin, on the other hand, is like pastry; it is rolled out as extensively and as thinly as possible, forming a thin coat.

Complexity of the Skin

The entire skin weighs twice as much as the liver or the brain. It receives one-third of the circulating blood, and its surface extends over 20,000 square centimetres (3,100 square inches). In each one of these 20,000 square centimetres we find in abundance the various structures grouped around the human head in Figure 318. Within each such area there are 100 sweat glands, 15 sebaceous glands, and hundreds of signal apparatuses; 39 inches of blood vessel and 156 inches of nerve can be removed from a piece of skin as large as a postage stamp, and each such piece is composed of three million

cells. In order to calculate the total number of organ structures contained in the skin the numbers given in Figure 318 must be multiplied by 20,000.

Human Leather. The skin consists of two tissue layers [Fig. 316], a thicker deep layer of interwoven connective-tissue fibres (the corium) (II), and a superimposed delicate membrane (epidermis) composed of epithelial cells (I). Every one of us has already become acquainted with the difference between the corium and the epidermis. If we burn ourselves, some fluid collects between the two layers, and the epidermis is elevated to form a blister. The peeling of the skin after a sunburn is likewise due to a shedding of the epidermis, which peels off like very thin tissue paper.

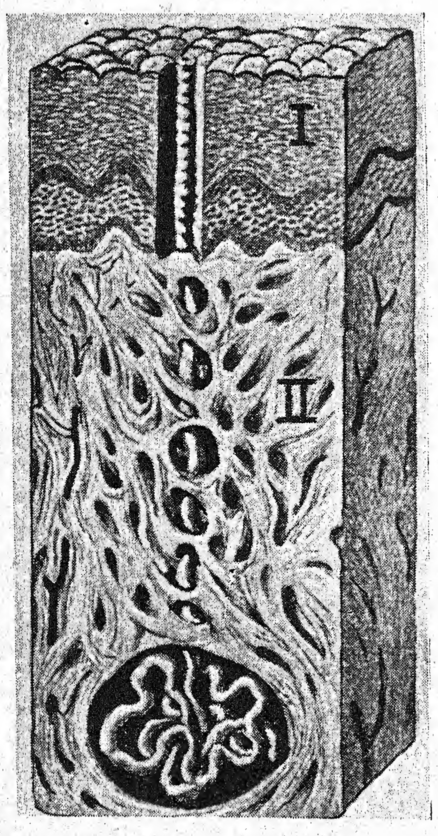


FIG. 316. *The basic structure of the skin. There are two layers: (I) the epidermis and (II) the underlying, fibrous corium.*

A Grim Present

We are also well acquainted with the corium, since leather is skin from which the epidermis has been removed in the process of tanning, leaving the corium. If human skin is tanned, one obtains leather which is so similar to the kid leather made from goatskin that the two may be confused. Human leather is very beautiful, even finer and softer than kid, and it is comprehensible that barbaric peoples made war cloaks out of the skins of the enemies whom they killed in battle. It was probably not a very pleasant sensation to face an enemy arrayed in a human skin and to think that perhaps several days later you yourself would be dangling from his shoulders as a flapping cloak.

It is said that the Venetian Governor of Cyprus was flayed alive by the Turks, who stuffed the skin, dressed it in his uniform and decorated it with the orders of the Governor, and sent it to the Sultan at Constantinople. The Hussite leader Ziska ordered a drum to be made from his skin, "so that you shall fight as victoriously when it sounds as if you had heard my own voice."

The Ridges of the Skin. In cold-blooded animals the epidermis lies smoothly upon the corium. In mammals, however, these two layers enter into a more intimate union. The corium buckles where it meets the epidermis, forming connective-tissue pegs known as *papillæ* that project into the upper layer, which

is moulded over them, thus creating a firmer and more intimate attachment. Among the lower vertebrates these pegs are scattered at random. In the ape family they are arranged in rows; corresponding to these rows the epidermis is elevated, forming parallel ridges [Fig. 315 (g)]. If one examines the tips of the fingers, one sees a network consisting of such ridges. These are the tactile ridges which contain the "touch" receptors of the skin. These sensory apparatuses are installed in such a manner that their position is not shifted by pressure or traction on the skin, with the result that the stimulus image derived from the sense of touch is not distorted [Fig. 315 (k)]. The width of the ridges is constant for every person and amounts to 1 : 2222 of the height of the seated individual. From the fingertips to the wrist there are three hundred ridges.

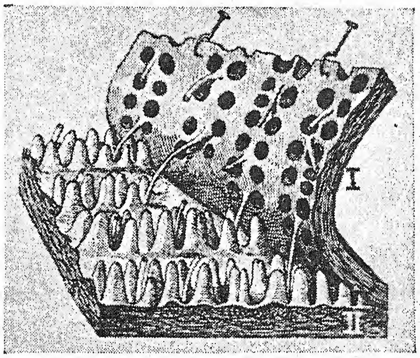


FIG. 317. *The epidermis (I) is attached to the corium (II) by innumerable minute cones composed of connective tissue. These cones, arranged in rows, elevate the epidermis, producing the characteristic ridges of the skin.*

Changeless Characteristics

Fingerprints. Put a trace of fat on the tip of your finger and press it against the surface of a clean plate. In this way one obtains a negative impression of the ridges or, as it is commonly called, a fingerprint [Fig. 320 (a)]. This is characteristic and unchangeable for every person. If the skin of the fingertips is burnt several times in succession, as two physicians have done in the service of science, the same fingerprints appear each time after the burns heal. The identity of the fingerprints can be proved by superimposing their enlarged photographs without obtaining any blurring.

Dactyloscopy. The Asiatic peoples discovered the individuality and immutability of fingerprints very early, and since ancient times employed them for signatures and seals. In Biblical Nineveh bills were receipted by a fingerprint. Europeans learned the method in eastern Asia, where it was employed for the personal identification of plantation workers and to prevent any confusion of identities in quarantine stations. In Europe the authorities in all countries refused to recognize this simple as well as reliable method for many decades.

Not, however, until the famous English scientist Galton had agitated energetically for many years was it possible to overcome the tenacious resistance of the bureaucrats and to elevate dactyloscopy to an internationally recognized means of identification. We human beings deserve no credit for dactyloscopy, since we did not invent it, but only discovered it. We can therefore truly say that it is a real miracle, both of nature and of mathematics. On comparing a rather large number of prints, one hundred different characteristics may be detected without difficulty In order to find two

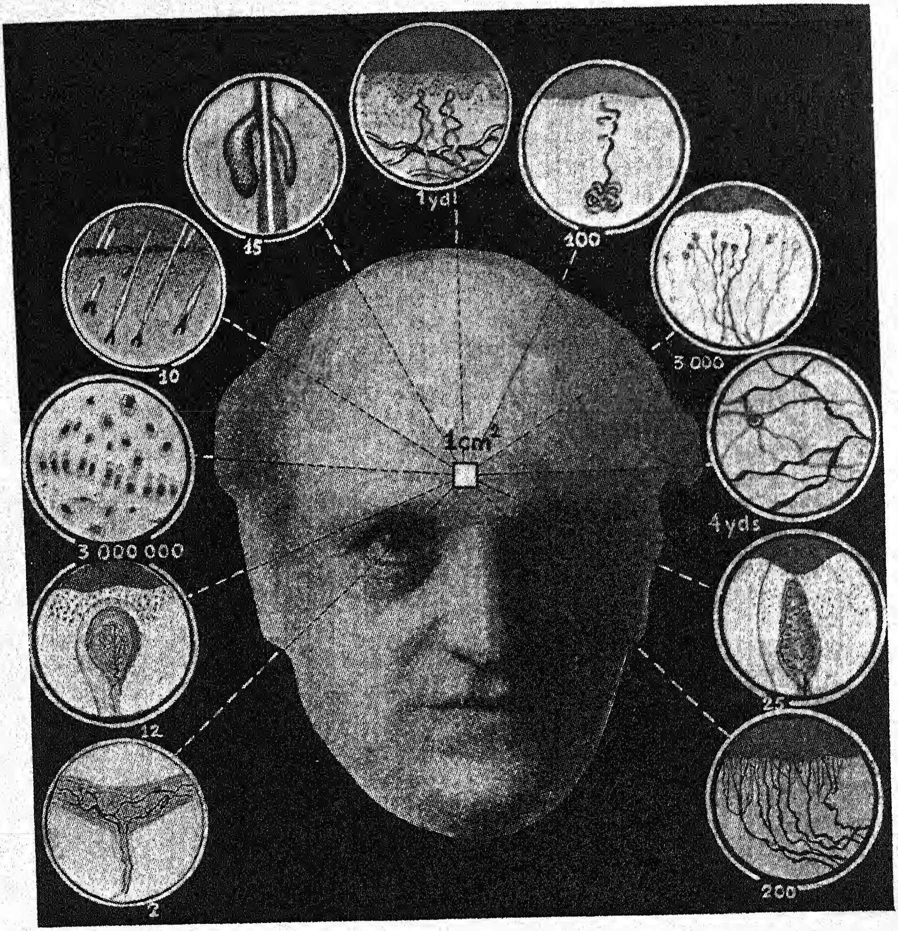


FIG. 318. *The amazing complexity of the human skin. One square centimetre of skin contains (from left to right): 2 sensory apparatuses for cold, 12 for heat, 3 million cells, an average of 10 hairs, 15 sebaceous glands, 1 yard of blood vessels, 100 sweat glands, 3,000 sensory cells at the ends of nerve fibres, 4 yards of nerves, 25 pressure apparatuses for the perception of touch stimuli, and 200 nerve endings which record pain.*

people whose index-finger impressions correspond in *two* characteristics it is necessary to examine an average of sixteen individuals. To find two people whose fingerprints resemble each other in three characteristics, sixty-four persons must be examined. Four corresponding characteristics on one finger are found once among two hundred and fifty people, ten such similar characteristics once among a million people, and seventeen among seventeen thousand million. In order to find another finger with the same *hundred* characteristics, one would have to observe the history of the world for four thousand million years before a second person would appear with the same print on *one* finger.

Man, however, has not *one* but ten fingers, and each one, as we can prove by examining our own fingers, has a different arrangement of ridges.

The greater the number of characteristics involved in any investigation, the more complicated is the work involved. Consequently, for practical purposes criminologists have restricted themselves to the twelve most striking characteristics. In accordance with the suggestion of a Danish criminologist, special number symbols were introduced for the individual characteristics. Thus the results of a ten-finger examination are combined in a formula of the type exemplified in Figure 319.

33533	34556	222 $\frac{1}{2}$	14.15.18.17.5.	00062. 33.9 $\frac{4}{5}$	074.	× 3—64
1 $\frac{2}{3}$	9 $\frac{1}{5}$	$\frac{1}{3}$	1.3—73.6.	$\frac{5}{4}$ 41	10149	

FIG. 319. *A fingerprint formula, such as is in universal use among police forces.*

Such a formula can be telegraphed to police stations all over the world, and anyone who is registered with the police anywhere can be identified within a few hours.

The probability that these twelve characteristics on any one finger may occur in a second person is as 1 : 24 thousand million; such a case may occur once every two hundred years. However, since not one but all ten fingers are registered, such mistakes can be considered practically impossible.

The Achievements of Dactyloscopy. The dactyloscopic picture is so certain that an error in the identification of a person can be considered out of the question. If one finds a person's fingerprint on an object, one can be sure that this person has touched the object even though otherwise there may not be even the slightest indication of his having done so. A dactyloscopic miscarriage of justice is impossible.

The Eternally Youthful Skin. The epidermis [Fig. 315 (A)] contains no blood vessels. Only its nethermost cell layers (b) are supplied with nutritive materials and are alive. They are very industrious; it is their job to produce cells on a conveyor system. The growth of the epidermis takes place by a multiplication of the cells of the deeper layers. The daughter cells are pushed upward by the mother cells. In the course of this process they are removed from their sources of nutrition and die. In consequence they undergo a chemical transformation, the protoplasm of the cells being converted into a horny material. The lower half of the epidermis (b) consists of cells that produce cells, the upper half (a) of cells that have died and have been converted into horn. The human body may be regarded as a house covered with horn shingles. Horn is an ideal protective substance. It is light, insensitive, impermeable to water, and a good electrical insulator. The uppermost layers are detached at the same rate at which the lower layers produce new cells. The skin manufactures many billions of new cells daily and sheds as many billions of dead horn plates. The clean stockings and underwear that are put on in the morning are covered in the evening with detached horn plates from the skin.

If water is examined after it has been used for washing, hundreds of horn cells will be found floating about in it like infusoria in the water of a pond. This uninterrupted detachment of the uppermost layers and the equally uninterrupted regeneration of the nethermost layers of the skin is the secret of the indestructible, eternally young skin. Reflect for a moment: an ink spot on a tablecloth is a major disaster for any housewife since the spot cannot be removed; a lace dress that has been soaked by rain is ruined; a grease spot on a light leather handbag cannot be eradicated, no matter whether we rub it or use a spot-remover or try some other method. But our skin is different; ink, grease, and iodine, silver nitrate or caustic soda, tar or rust have all stained our skin at one time or another. Today we take apart a motor-cycle or a typewriter; tomorrow we may be plastering a wall; in the morning the housewife peels potatoes and cleans vegetables, and in the afternoon her hands are immersed in hot soapsuds; the skin is scratched, cut, singed, and cracked—yet it always becomes as new and beautiful and clean as it was in the beginning. This eternal youth of the skin is due to the horny layer, which we rub off with its dirt and scratches whenever we wash, and beneath which there is always a new horn layer ready to become dirty again, to be scratched, abraded, and corroded. The human skin is a tear-off pad with thirty layers of horn cells. The uppermost one becomes dirty [Fig. 322 (a)]. We go to the washbasin, rub it off (b, c, d), and now the next page lies beneath it (e). Yet the block is never used up, for while we are using the top leaf, a new leaf pushes up from the lowest layer. Consequently when we have rubbed off the thirtieth leaf on top, there are again thirty leaves and not twenty-nine beneath it. This is indeed an "eternal pad" from which we can

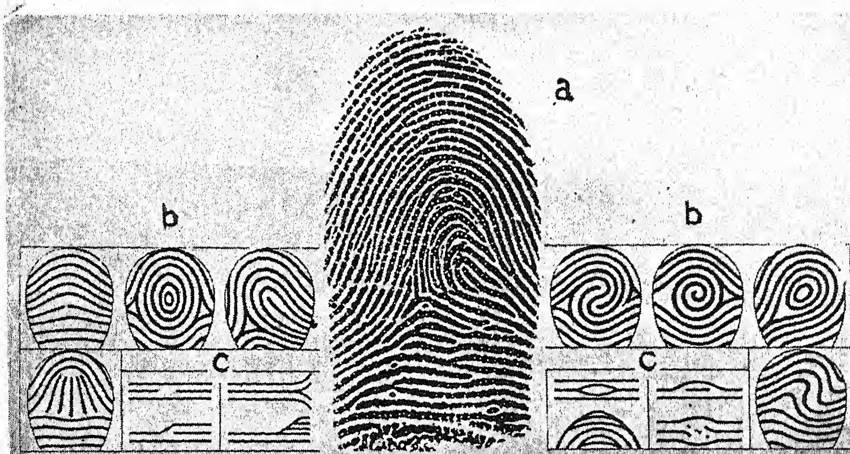


FIG. 320. *Fingerprints, used for identification, are impressions of the skin ridges on the fingertips. At (a) is an enlarged natural print; at (b) are shown differing types of ridge patterns; at (c) are typical figures which interrupt the ridges.*

tear off a page six times a day without decreasing its thickness in the course of a lifetime.

The History of Cleanliness. Washing with soap is a relatively recent practice. The people of classical antiquity took care of their skin, but they were not yet acquainted with soap, and consequently employed the bothersome methods of sweat bath and massage. It is for this reason that baths occupied such a large place in the daily lives of the people of antiquity.

A Lost Art

During the dark period of the Middle Ages the art of caring for the skin was lost to a large extent, along with the ancient mode of life. At the court of the famous Catherine de' Medici there were no washing facilities. Within six years the court changed its seat ninety times, so that the filthy rooms could be rendered habitable once more. The Escorial, the palace of the Spanish kings, contained three thousand rooms, but no bathroom. In the palace of the Sun King at Versailles there was likewise no bathroom. The only bathtub present was placed in the park and converted into a fountain, because no one used it. Naturally, the people of that period also cleaned themselves, but at irregular intervals; and instead of washing they perfumed themselves several times a day. No wash-stand is to be found in the Goethe House at Weimar; the great poet washed himself in a basin no larger than a dessert bowl, using a wet sponge [Fig. 323]. In the course of the nineteenth century wash-basins grew larger, but as slowly as Japanese dwarf trees. The splendid dwelling of Richard Wagner lacked a bathtub, but in contrast to Goethe's washing facilities Wagner had a small wash-stand, and the "dessert bowl" washbasin had grown to the size of a small tureen

Microscopic Mechanism

The Hair. Two special appendages develop from the horn layer: the nails and the hair. A hair develops as a small, solid down-growth of the epidermis which descends into the corium, strikes root there, and then like a tulip bulb shoots upward, pushing its way through the layers of the epidermis, which it finally perforates. In Fig. 315 at (d) we see a hair under low magnification: (d) the shaft, (e) the hair gland, which lubricates the hair with its fatty secretion, (f) the hair muscle, which erects the hair and compresses the gland so that its secretion is distributed over the shaft, keeping the hair soft and supple. The mechanism of this lubrication as well as the erection of the hair as a result of cold, fear, or disgust, creating the condition known as "gooseflesh," have been described already (page 103 and Figure 87). The finer structural details of a hair are shown in Figure 326.

Development of Hair

Like the epidermis, from which it is derived, a hair also consists of a cellular tissue [Fig. 326 (K)], which forms the "soil" in which it grows, and the horny shaft (H), which is nourished and pushed upward by this "soil." Above, at the level of the letters (H) and (K), both parts are sharply differentiated; below, in the region of the root [Fig. 326 (P)], they merge. Here one sees the four layers (I-IV) (at the left in cross-section, on the right in longitudinal section), and in them one recognizes

the cells which, by dividing and multiplying, push the hair shaft upwards through the skin. As they move away from the growth zone the hair cells become converted into a horny material like those of the entire epidermis. They survive longest in the centre of the hair as the medulla [Fig. 326 (m)]. On the outer surface of the hair (page 474, upper centre) the cells are flattened like fish scales and lie on top of one another like shingles, thus giving the hair a metallic appearance. At the outer edge of Figure 326 (left) is the hair muscle, and surrounded by it is the fat gland of the hair. (N) indicates the nerves that surround the root of the hair, and beneath the letter N we see the large spherical fat cells from which the cells obtain the materials for constructing hair.

The Screw Membrane

An interesting accessory structure is the "screw" membrane, which is seen on page 475 near (III) and also appears at (S), on page 474. The "screw" membrane is a glassy membrane equipped with a screw thread, by means of which the hair root is screwed firmly into the tissue so that it cannot be torn out. If one pulls out a hair, it is the horn shaft which can be regenerated that is torn out. The irreplaceable germinal layer, however, cannot be torn out, because it is screwed in firmly.

FIG. 321. *Many hundreds of years ago, Eastern races used fingerprints for personal identification. This ancient Chinese document is sealed with a fingerprint.*

The Tensile Strength of the Hair. Since the hairs are so ingeniously screwed into the skin, they can withstand strong traction. Their tensile strength is equal to that of zinc. A strong, single hair supports 1.8 to 2.8 ounces, and the entire hair of the head can support as much as 3,600 to 5,400 pounds [Fig. 325]. Chinese acrobats swing by their hair on a high trapeze and can do it without worry, because before a well-developed pigtail tears, ten to twelve people have to hang on to their feet.

The Colour of the Hair. Among the germinative cells of the root live cells that contain pigment. These cells also multiply; their daughter cells wander upwards with the growing hair shaft and die, leaving the pigment granules in the hair. They exhibit all shades of brown, from a reddish colour to a deep black-brown. The horn substance of the hair, in which the pigment is embedded, is yellow. The colour of the horny material and that of the pigment granules mingle, giving rise to the infinitely varied shades of human hair, from blonde to black.

The Greying of the Hair. The greying of the hair is a process which is still unelucidated. It is not due to a disappearance of pigment, but to the appearance of air cavities among the medullary cells of the hair. The origin of these air bubbles and the causes underlying their appearance are still disputed. Nervous excitement favours the entry of air; worries, cares, and sorrow lead to premature greying of hair.

The Number of Hairs. Man has 300,000 to 500,000 hairs in his skin.

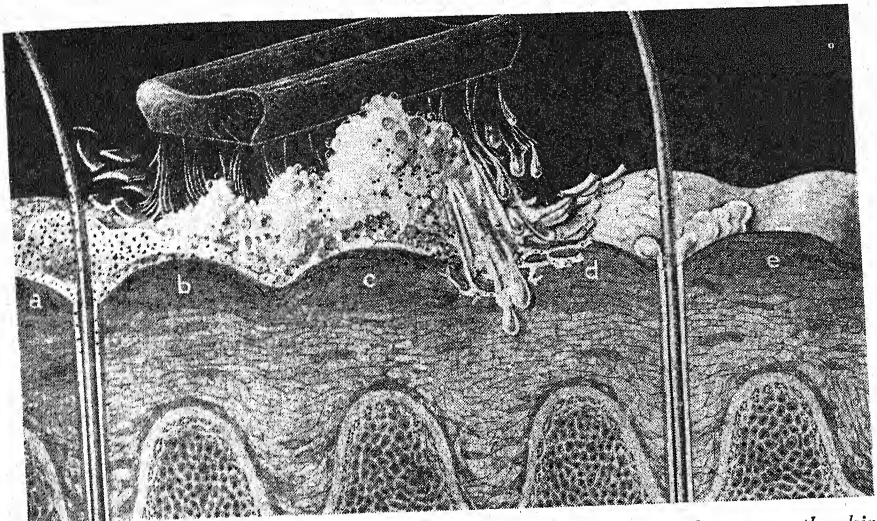


FIG. 322. *How soap cleanses the skin. A fatty layer, mingled with dirt, covers the skin and closes the pores (a). When the skin is scrubbed with a brush (b), the loose, uppermost layer of horn cells is removed mechanically. The soap forms innumerable bubbles (c), which attract the dirt particles by surface tension and thus remove them. The soap breaks up or emulsifies the fatty layer physically and dissolves it chemically (d). The skin is freed at last of its layer of dirt and grease (e). Soon a fresh supply of fatty material rises to the surface of the skin along the hair-shafts and covers the skin with a new layer of grease, which eventually will also be removed in its turn.*

Blonde persons with finer hair have a somewhat greater number, dark persons with coarser hair about one quarter less. Red-haired persons have the coarsest and consequently the fewest hairs. The density of the hair varies for the different skin zones, just as the speed with which the hairs grow varies from one area to another.

The Growth of the Hair. Hair grows at the rate of about half an inch a month, and about .01 to .02 inch daily. In the course of a day the rate of growth varies according to a certain rhythm. At night the hair grows slowly, but with the break of day the speed of growth increases, reaching its maximum between ten and eleven a.m. Then the hair grows slowly again until its growth is once more accelerated between the hours of four and six o'clock.

In order to obtain some conception of the hair-production of the body let us assume that the hairs do not grow out of the skin singly, but send their total substance into a hair cable, just as a climbing beanstalk grows out of its many roots. This universal hair would grow at a rate of 1.2 inches per minute. While one is asleep in bed at night, this universal hair could creep out of the window, in the course of a day it could wander across the street, and at the end of a year its tip could have travelled a distance of thirty-seven miles. In one year the human skin produces a "hair" equal in length to the distance covered by a train in one hour.

The Embryonal Hair. About the hundredth day of embryonal life a

thick coat of hair sprouts from the skin of the human fœtus. After another hundred days these hairs are shed, float about in the amniotic fluid, and are swallowed with the fluid by the fœtus. The first course at the banquet of nature consists of hair, and a human being's first meal is a cannibal meal. He consumes human tissue, a piece of himself.

Infantile Baldness

Some of these hairs remain undigested in the dark fæcal material, known as meconium, which the child evacuates after birth. Many embryonal hairs are shed after birth, and the child vexes its mother by becoming bald. If, as happens in exceptional cases, the hair coat is not shed but continues to grow, the abnormal condition known as congenital hypertrichosis results. Such individuals are seen in side-shows as the "lion-faced boy," and so on. Angora cats represent an artificially bred hairy race of this type among domesticated animals.

The Changing Hair. The embryonal hair coat is discarded and replaced by the delicate hair which is characteristic of the child. At the time of puberty this hair coat is transformed into the final, "terminal" hair coat which is peculiar to the adult.

Hair and Hormones

The location and development of this adult hair coat is regulated by the sex glands. The male sex hormone promotes the development of the beard and the body hair, while inhibiting the growth of the head hair. The action of the female hormone is just the opposite. In women exhibiting male tendencies one finds indications of a male distribution of hair, just as men with female characteristics tend to have long head hair. Despite many investigations the purpose of this third hair coat is not yet sufficiently understood. The hairs at the entrances to the body cavities, such as the eyebrows, lashes, ear and nose hairs, are apparently mechanical barriers against the intrusion of dust and insects.

Pubic and axillary hair is probably intended to retain and to spread the skin odours which serve as a means of attraction and excitation in the sex life of animals, but which no longer correspond to the tastes and habits of civilized man. The man's beard is a secondary sex characteristic, the function of which was probably to render the difference between man and woman evident at a distance, to indicate the sex of the wearer, and probably to give the male an appearance of power and dignity.

In Darwin's view, the fine hairs of the body are intended to serve as "gutters" for perspiration and rain water.

The Duration of Life of a Hair. The life span of individual hairs varies greatly. Eyelashes live hardly six months, the hairs on a man's head three to five years, and those of a woman an average of seven years. When the plaits of a fifteen-year-old girl extend to her knees, they still contain hairs from the first year of her life.

The Fatty Skin Cream. How does one take care of leather articles—for example, boots? They are greased every morning with polish so that the leather remains soft and pliant, does not become brittle and cracked, and is not affected by dust and moisture. The body treats the

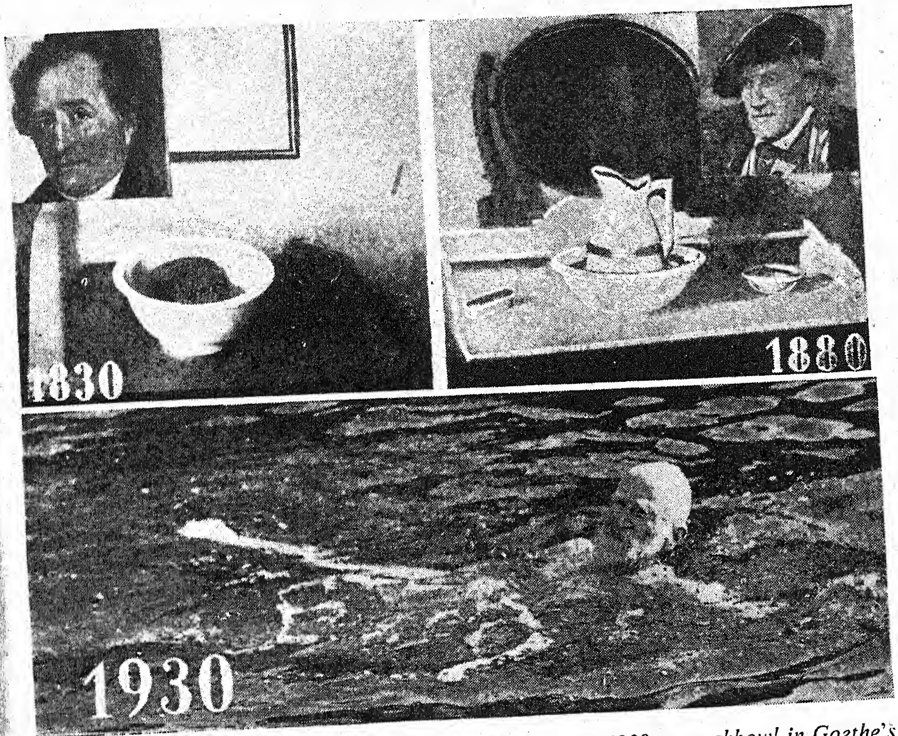


FIG. 323. *The slow development of skin hygiene. (Left) 1830: a washbowl in Goethe's house at Weimar. At this period baths and washstands were not yet in general use. The washbowls were not much larger than salad bowls. (Right) 1880: washing utensils used by Wagner fifty years later; the bowl is somewhat larger than Goethe's. (Below) 1930: George Bernard Shaw taking his daily swim at the age of seventy-four.*

"leather" that covers it, which we call the skin, in exactly the same way. Every hair muscle [Fig. 87; Fig. 315 (f)] is not only a barber who lubricates the hair with pomade daily, but also a bootblack who covers the skin with grease, thus keeping it soft and pliant [Fig. 327]. Not only is this fat the best isolating material against moisture, thus preventing cracking, but it is also a poor conductor of heat, thus helping to regulate the temperature of the body where it comes into contact with the external environment (a). It hinders excessive radiation of the internal heat of the body, and prevents the rays of the external environment from penetrating the skin (b). Owing to the fat layer, water does not wet the skin readily, but runs off it, thus preventing the rise of a cold feeling due to evaporation (d). As a result of washing with soap the fat layer is dissolved, and any remnants of it are removed when we dry ourselves with a towel. After washing, the skin lacks this oily layer and is much more sensitive to all noxious external influences than it was previously (e). During wet and cold seasons we cannot do without the protection of the fatty layer of the skin, and consequently after

washing we feel the need of replacing the oily layer which we have removed from the skin. By rubbing in some cold cream we give the skin an artificial fatty layer (f).

Sweat. The perspiration produced by the skin is the antagonist of the fatty secretion discussed above. The

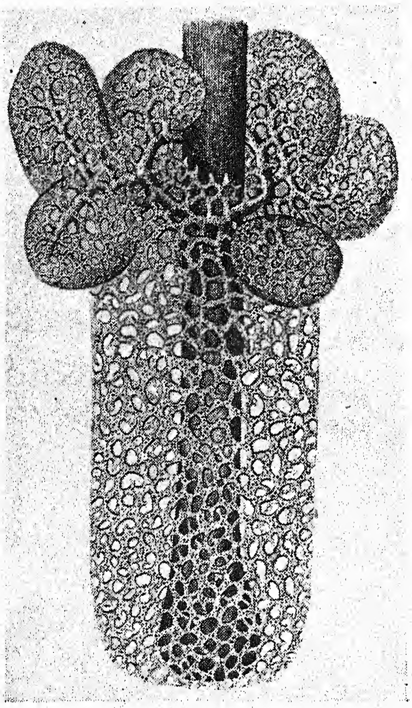


FIG. 324. *The hairs upon an average human head amount to more than 100,000. Each of them is set within a network of lymph vessels, which nourish its root.*

viscid and non-evaporating skin fat isolates the skin and protects it against any heat loss; the fluid, rapidly evaporating sweat, on the other hand, produces a heat loss due to evaporation and thus cools the surface of the body. Under normal conditions an individual loses 500 calories daily — one eighth of his total heat loss—as a result of the evaporation of perspiration. The sweat is produced in deep-seated glands. From the glands a long duct, which is spirally twisted as it passes through the epidermis, leads to the surface [Figs 315 (c) and 316]. The skin contains two million sweat glands. Turn over the pages of this book and estimate the number of letters; there are more orifices of sweat glands in your skin than there are letters on the pages of this book.

The Human Chimney

An imprint of the sweating skin looks like a stellar photograph, and yet these points are the products of a coalescence of hundreds of sweat-gland openings [Fig. 328]. Each sweat gland is $\frac{1}{5}$ inch long. If all the sweat glands were to be placed end to end, we would obtain a tube six miles in length; and if the cells that produce the sweat were put alongside one another, they would form a carpet covering an area of 53.8 square feet. If all the sweat pores were combined, the result would be a chimney as large as the smokestack of a locomotive. Through this chimney the machine, which is the human body, exhales "steam" uninterruptedly just like a locomotive.

The sweat glands are not distributed equally over the skin, but are more closely set on the forehead and the palms of the hands and the soles of the feet. The distribution on the hands and feet is due to the fact that perspiration is a substance which is of value in climbing. The ancestors of man were arboreal, climbing animals; and just as a climber spits on his hands before he climbs up a rope or a pole, climbing animals similarly sweat on their

palms and soles, so as not to slip when climbing. For this reason perspiration is also sticky.

If the sweat does not evaporate as fast as it is secreted, it becomes visible in the form of larger or smaller drops. This is known as *sensible* perspiration. If it evaporates without becoming visible, it is known as *insensible* perspiration. Most sweat passes off in this latter form, no less than one quart being given off in a single day! Don't simply read this fact, but try to get some conception of what it means. Take a pot from the kitchen and fill it with a quart of water; so much perspiration passes off from the human body on a day when a person is inactive. If a person works hard, marches in the heat of the sun, or sits in an overheated motion-picture theatre or lecture hall, he loses many times this quantity. As much as twenty quarts of perspiration can be excreted by the skin in one day!

The "Third Kidney"

As is well known, perspiration is acid. It contains salt, potassium, iron, sulphuric acid, phosphoric acid, lactic acid, and, above all, urea. The skin excretes as much urea as a kidney, so that it has been correctly described as a third kidney. If one prevents the skin from giving off heat, sweat, and waste products, the body dies from poisoning and overheating.

The Acid Coat. Not only is the perspiration acid, but the decomposition of the oily layer of the skin also yields acids, so that the human skin is covered by an acid coat which apparently fulfils an important function. In the first place it prevents the development of fungi and bacilli on the skin, since most of these micro-organisms do not flourish in an acid medium. The body has two acid barriers: the acid-coated stomach as a protection for the intestinal canal, and the acid layer of the skin as a protection against the parasites of the air. This acid coat very likely plays an important, although to a large extent still unknown, part in the electrical processes on the surface of the body.

FIG. 325. *The tensile strength of hair is very great. A well-developed head of hair can support 3,000 pounds or more, so that Chinese acrobats can swing from a trapeze by their hair without fear of falling.*

The Skin as Receptor of Radiation. Man has lost the hair coat of the animal; in place of it the skin has gained a new function. It has become an organ adapted to receive and to utilize radiation, for no higher organism has such direct relations with the radiant energy of its environment as man, whose nakedness is not a primitive condition, but

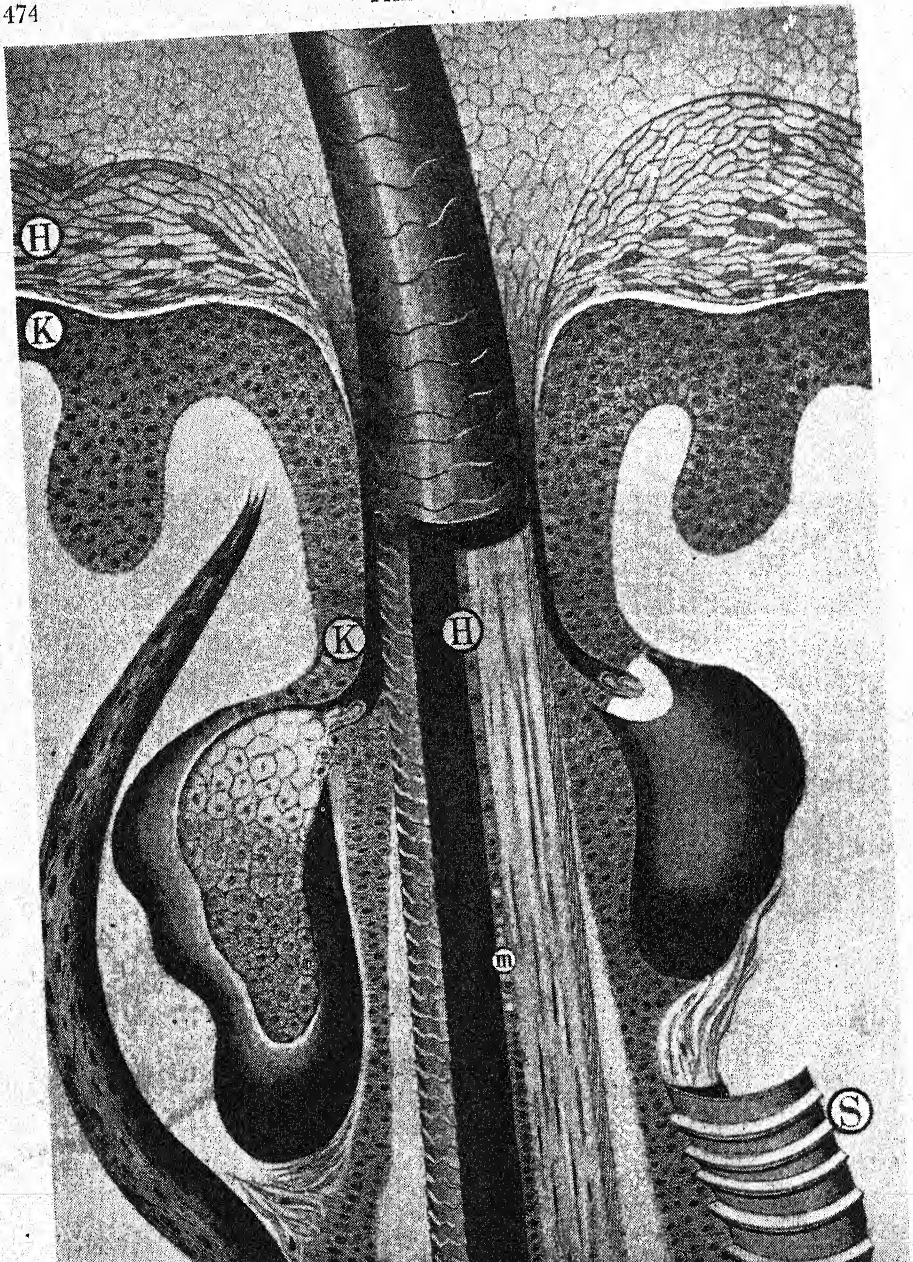
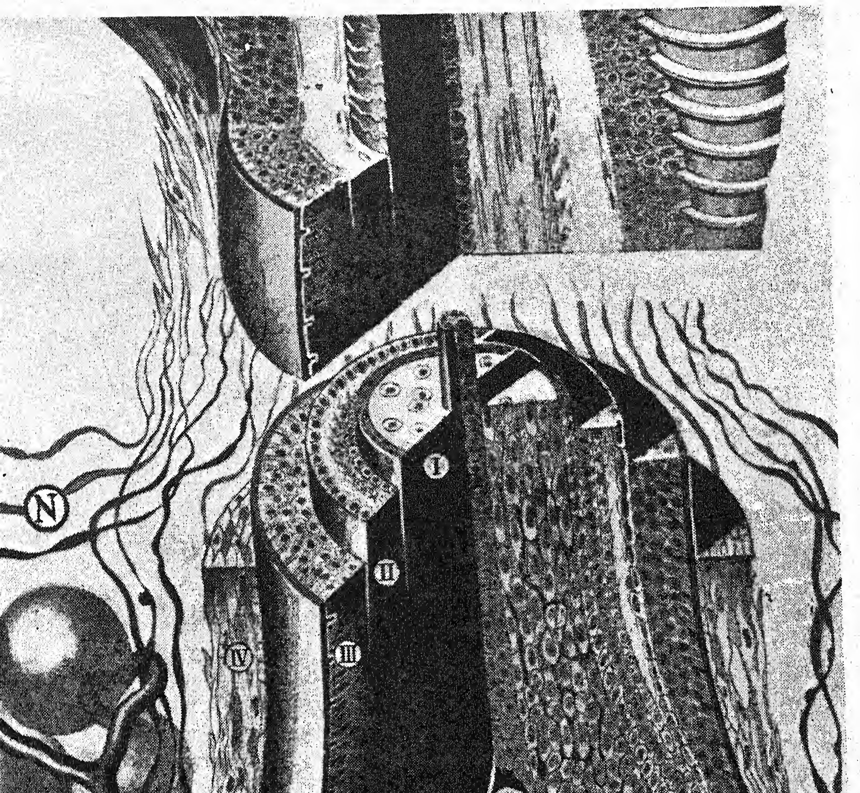


FIG. 326. *On this and the opposite page is shown the internal structure of a hair. (H) indicates the horny layer of the skin and the horny hair shaft. The "screw"*



membrane (S) anchors the hair into the skin. Above are the base of the hair and its root. At (N) are nerves of the hair; below them are globular fat cells and blood vessels.

the result of a long historical development from animal to man. The ten most important effects of light on the human skin that have been discovered until now are as follows:

1. *Erythema or Redness of the Skin.* Ultra-violet light produces the condition known to us as sunburn, by transforming histidin, which is contained in the epidermis, into a substance that dilates the blood vessels, thus causing the skin to become red.

2. *Tanning of the Skin.* Ultraviolet light acts on the tyrosin which is present in the skin, transforming it into the brown pigment melanin, which is deposited in the superficial layers and protects the skin against the further action of the light rays. The pigmented, undulating layer of cells between the germinal and the horn zones is clearly visible in Figure 322.

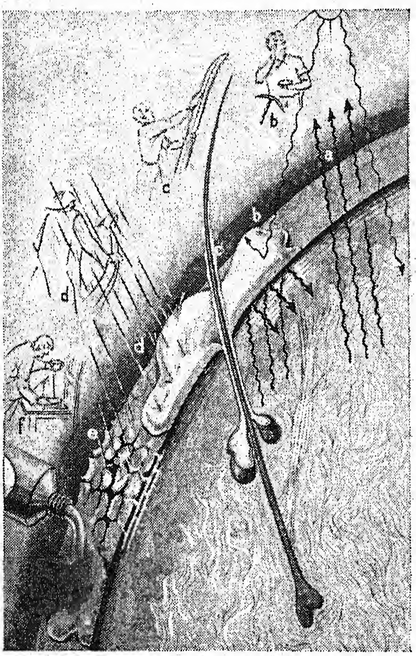


FIG. 327. *The skin secretes a fatty material which prevents excessive loss of body heat (a) as well as excessive heat absorption from outside (b). The greasy coating (c) keeps the hair and skin supple and prevents penetration of moisture (d). A dry skin becomes brittle and cracks (e), so that we must substitute skin cream when the natural grease is absent (f).*

Lack of Pigment

The Albino. Like all chemical processes in the body, pigment formation depends on the action of enzymes. Organisms that lack these enzymes are unable to form any pigment and in consequence remain colourless. Such organisms are found in all animal groups and are known as albinos. Since the iris of the albino has no pigment, it becomes translucent, so that the reflection of the light by the reddish retina gives the eye a pink appearance. White mice and rabbits have pink eyes. The eyes of the albino are not protected by pigment, so that they receive an excessive amount of light. In an attempt to exclude some of the excessive light the albino tends to shun the light (photophobia), and is continually screwing up his lids and frowning.

Sunlight Versus Disease

3. *The Bactericidal Action of Sunlight.* Sunlight causes protein to decompose and consequently exerts a bactericidal action, destroying fungi and bacteria that may have settled on the skin. The tubercle bacillus and the gonococcus are very sensitive to the sun's rays and are rapidly destroyed by sunlight.

4. *Increase of Blood-Pressure.* The action of sunlight on the skin also produces a substance which contracts the blood vessels of the skin

and thus raises the blood-pressure. On this account persons who must avoid any rise in blood-pressure, such as cardiac and pulmonary patients, should be very cautious when taking sun-baths.

5. *Stimulation of the Phagocytes.* After radiation of the skin the wander cells become more active and their phagocytic activity is increased. The cells in the walls of the smallest vessels, such as those shown in Figure 137 also become more active. If one infects animals experimentally, keeping one group of animals in the dark and the others in a light place, the latter will be more resistant to the infection.

Winter Ailments

The greater frequency of infectious diseases during the winter months, when the amount of sunlight is reduced, is undoubtedly connected with a decreased phagocytic activity of the wander cells and a diminished formation of immunizing substances, although other factors, such as cold, frequent changes of the weather, increased humidity, insufficient vitamins in the food, and so on, play an important part.

6. *Increased Tonus.* Under the influence of light, the skin sends substances into the blood which increase the tonus of the musculature. Poets of all nations have extolled the virtues of light, which gives greater energy and joy of life. Through the discovery of the tonus elevating substances modern science has confirmed the justification of this feeling. At high altitudes the tonus of the musculature is measurably increased, the muscles become tenser and more prominent under the skin, posture is improved, and the movements of the body exhibit greater refinement.

7. *Vitamin D.* Ultra-violet light transforms the ergosterol in the skin into vitamin D, as described above (page 324) and shown in Figure 230.

Electric Currents

8. *Charging the Nervous System.* The various layers of the skin contain numerous nervous apparatuses [Fig. 315 (k), (l), (m)]; in addition millions of nerve fibres terminate in knobs and tips located between the cells of the epidermis. Some of these mechanisms may be compared with the photo-electric cells of television machines. When light impinges on them, electrical currents arise in them. Radiation of the skin stimulates the individual, makes him more active and desirous of moving about. This is one of the reasons why people who go on holiday in the summer become so remarkably active—play games, exercise, go swimming and riding, and in general move about a great deal.

9. *The Light Hormone.* When the abdomen of a frog is stimulated by light, even though the eyes are not illuminated they will still react reflexly and accommodate themselves to the light. This reflex is not the result of neural action, but is due to a substance which arises in the skin under the influence of the light and is carried by the blood to the organs.

The Light Hormone

That this is so can be proved by transfusing the blood from the illuminated frog into one that has been kept in the dark, whereupon the latter's eyes will also exhibit the accommodation reaction. This substance is called the light hormone.

It increases the functional capacity of the muscles and sense organs. If a man in a dimly illuminated room is shown several grey plates, and at the same time light is directed upon his uncovered legs, the plates will appear lighter to him; similarly his auditory acuity will also be increased. A person exposed to light hears, sees, and acts better than one who is in the dark.

Sensitization

10. *The Light Substance, Porphyrin.* Whoever has occupied himself with photography knows the concept of sensitization. Films become more sensitive to light after having been saturated with fluorescent substances. The sensitizer increases enormously the normal effects of light. The best-known sensitizer is the green chlorophyll of plant leaves. Without this sensitizer the plant is unable to carry out the apparently difficult process of synthesizing sugar and starch from carbon dioxide and water. Chlorophyll is chemically related to the blood pigment hæmoglobin, which is likewise a sensitizer. Blood exposed to the rays of the sun is extremely " active." Perhaps the great sensitivity to light of blonde persons is due to an excessive sensitization.

When Light is Harmful

Hypersensitiveness to light occurs among both human beings and animals. Patients suffering from smallpox are extremely sensitive to it and are kept in a room provided with red glass to exclude the ultra-violet rays. Some people develop swellings of the face and hands, so-called angioneurotic œdema, when exposed to light. Most striking of all, however, is the sensitization which follows the injection of hæmatoporphyrin. This substance is a derivative of the blood pigment and appears to act as a photographic sensitizer. When a white rabbit is injected with hæmatoporphyrin and kept in the dark or in a room from which ultraviolet radiation is excluded by means of red glass, nothing happens because hæmatoporphyrin as such is not a poison. If it is exposed to light, however, an acute inflammation of the skin as well as excitement and convulsions develop within a few minutes, as a result of which the animal dies in about three hours.

Light Sickness

Farmers are familiar with this light sickness. If domestic animals are fed during the winter with buckwheat, which contains a fluorescent pigment, and the animals are allowed out on the fields in the spring, they are attacked by the " buckwheat disease." On the other hand, if the animals are not fed with buckwheat for several weeks before they are released from the barns, so that the pigment is to a great extent eliminated, the animals remain unaffected.

White rabbits injected with minute doses of hæmatoporphyrin suffer no severe reactions on exposure to light, but instead are stimulated. They are very active, jump about vigorously, eat enormously, exhibit great sexual activity, and increase in weight. Similarly traces of hæmatoporphyrin produce remarkable improvements in the dispositions of human beings, so that attempts have been made to use it therapeutically in cases of mental depression.

Massage of the Skin. The effect of massage on the connective-tissue

fibres and the blood vessels has already been discussed above. With respect to the skin, massage produces the following effects: the circulation of the blood is increased, thus improving the nutrition of the skin and rendering easier the removal of waste products; the blood vessels are exercised; the sensory apparatuses and the reflexes are stimulated, the sweat and fat glands are compressed, and the pores cleansed; the oil which is used for massage is rubbed into the skin, rendering the epidermis supple and pliant.

Tub Bathing. An almost complete substitute for massage is a daily washing of the skin with cold water, and healthy young people should be trained to start the day in this manner in both summer and winter. The skin is soaped superficially, and then immediately rubbed down with a stiff brush. The entire procedure must be brief and take place rapidly since a very prolonged action of the soap is undesirable.

Potent Medicine

Sun-Baths. A sun bath produces all the effects that have been listed under the actions of light. In order to understand the problem of the sun-bath one must remember that sunlight not only acts on the parts of the skin that are directly exposed to it, but also produces substances in the irradiated skin which pass with the blood into the interior of the body and act on the entire organism. If one's feet are exposed to the sun's rays, substances that elevate the blood-pressure also excite the heart, vitamin D passes to the bones, and hæmatoporphyrin stimulates the cells of the cerebral cortex. Exposing one's skin to the sun's rays is equivalent to swallowing a teaspoonful of medicine every five minutes, and a medicine which is by no means harmless. For this reason one must be just as cautious in taking a sun-bath as in taking a medicine obtained at the chemist's. Sun-baths may be absolutely fatal to persons suffering from pulmonary disease. For this reason sanatoria in the

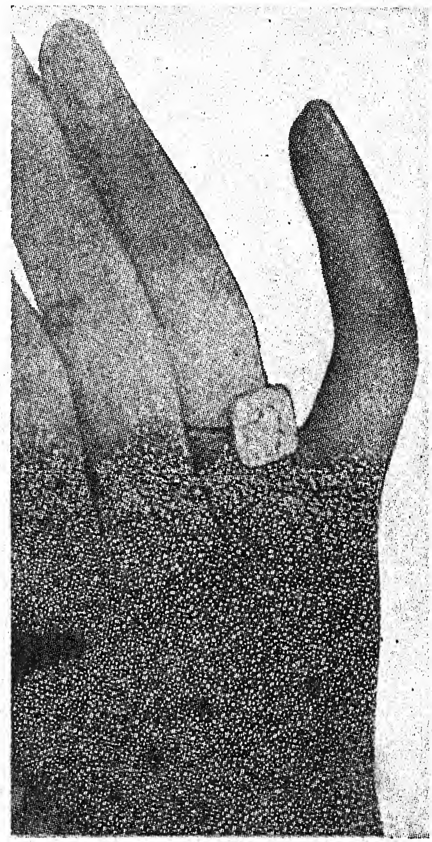


FIG. 328. *Imagine that each of the dots on this hand is a chimney. Thus would the human skin appear to an observer with microscopic eyes—a view like that of an airman who looks down upon a city. He sees no details, yet the chimneys of the cell-city, through which the smoke of the gland furnaces pours ceaselessly, are as closely crowded together as the dots.*

mountains have a rigid rule that patients with lung trouble must lie in the shade and not in the sun.

Holiday Rules. A holiday should last at least three weeks, since it takes seven to twelve days to adapt oneself—that is, to acclimatize the skin, the blood, and the heart to the changed environment. When one takes sun-baths, one should begin by exposing only one fifth of the body for five minutes. The next day the time of exposure is increased by five minutes, another fifth of the body being uncovered during the additional—that is, the last—five minutes. In this way the body receives slowly increasing doses of sunlight and the various rays which it contains in such great richness.

Biology has its own mathematics; short sun-baths exert a stronger action than long ones. If one wants to take advantage of the therapeutic action of the sun, one must ascertain the optimum time of exposure at the particular place where one is; this optimum time depends upon the radiation intensity there. At high altitudes with a clear sky the maximum effect is achieved after fifteen minutes. Longer baths tire the skin and exhaust its chemical energies, so that it is not helped, but injured. Persons whose occupation exposes them to bright sunlight for long periods, such as mountain guides, seamen, and farmers, have a

FIG. 329. *Sunbathing today—and as it used to be in the early years of the present century, before the importance of solar radiation for the human body had begun to be properly understood. Lying in the sunshine is of comparatively small curative value so long as the greater part of the body is swathed in garments which effectively prevent the health-giving rays of sunlight from penetrating the skin. The girl on the right is a product of healthier and more enlightened days. By exposing a large area of her skin to the sunlight she is benefiting by the vitamin-producing, disease-destroying rays which the sun ceaselessly pours out in such boundless profusion.*

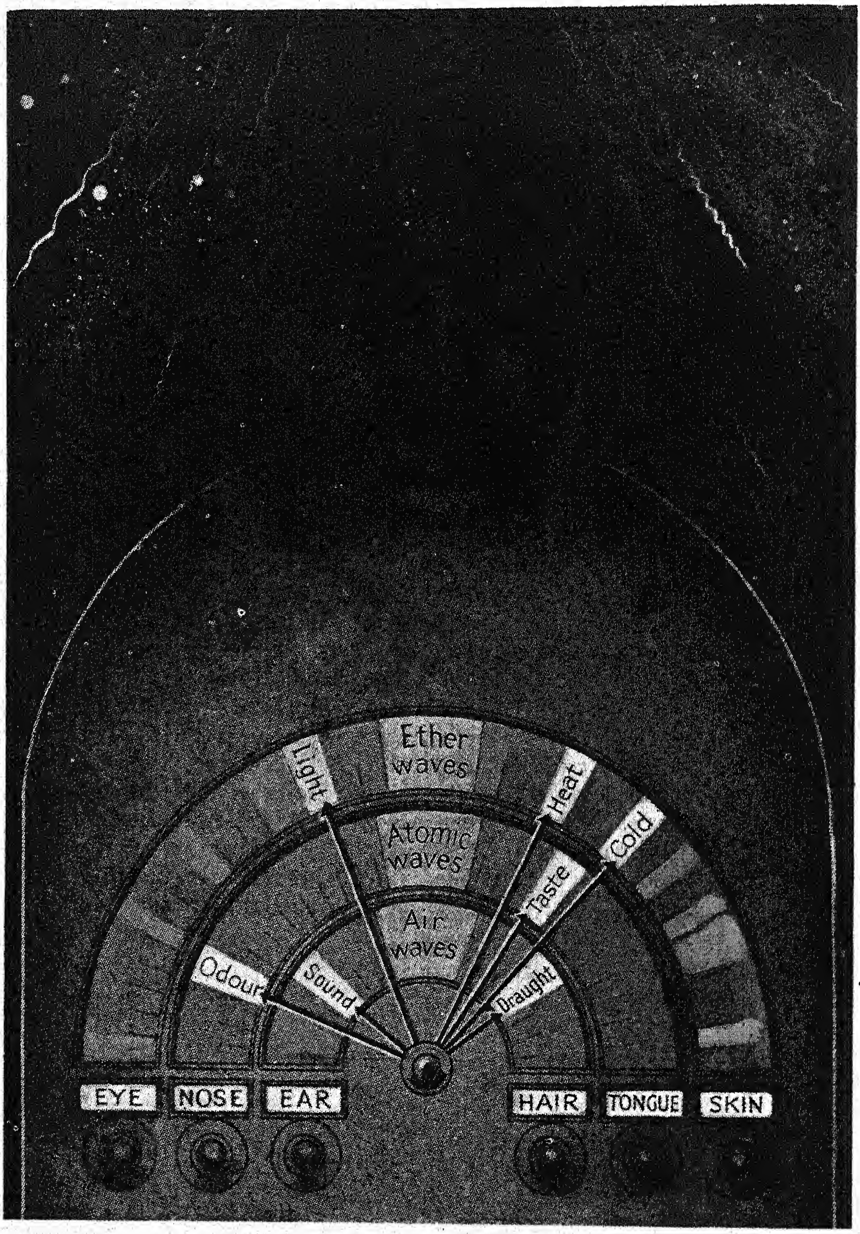
weathered skin, and often develop thickened patches on the skin of the face and hands which not infrequently form a starting-point for cancer. The head should be kept covered, or in the shade, under all circumstances, so that an excessive accumulation of blood in the meningeal blood vessels will be avoided. Every once in a while we hear of "heart attacks," which are really cerebral hæmorrhages, among young, resistant persons who are taking a holiday in the mountains, because they have gone from a sun-bath directly into cold water. The circulatory system which has been subjected to the strain of a sun-bath, and is perhaps tired, cannot adapt itself so quickly to the completely different conditions in a cold bath. For this reason, after a sun-bath one does well to wait awhile before entering cold water.

Light Starvation

Light at Present and in the Future. Modern urban man lives in a world which is deprived of a great deal of light and radiation. Only a part of the light of the sun penetrates between the high city houses into the depths of the streets, or through the windows of the schools and workshops. The important ultra-violet rays of sunlight are absorbed to a large extent by the dust layers of the atmosphere, the smoke, and the gases from motor-car exhausts. Even in the upper storeys of the houses not a trace of ultra-violet radiation passes through the window-panes of the closed rooms.

Looking Forward

The twentieth century, the century that has conquered the air, should, and in all probability will, be the century of the conquest of light. Our present-day cities with their dark canyon-like streets must disappear. People must realize that the upper storeys of houses are the more valuable ones. Tar-covered roofs must become roof-gardens and playgrounds for both adults and children. A time will undoubtedly come when people will look at our present-day houses, shake their heads, and wonder how anyone could have lived in such "holes," just as we do when we see the rooms and the curtained wooden beds of our seventeenth-century ancestors.



MAN, ENERGY, AND THE UNIVERSE

FIG. 330. *Numberless ether waves of various types—heat, light, radio activity, cosmic radiation, and many more besides—pervade the entire universe from end to end, and ceaselessly stream into the atmosphere of our planet. Even with his special senses man can perceive only a minute fraction of this vast outpouring of energy.*

CHAPTER XXXVII

The Sense Organs of the Skin

MAN AS A RECEIVING APPARATUS. PAIN. TOUCHING, STROKING, TICKLING. TACTILE IMPRESSIONS. THE BRAILLE ALPHABET FOR THE BLIND. RECORD ACHIEVEMENTS OF THE TACTILE SENSE. "THERE'S A DRAUGHT . . ." TRACTION AND DISTORTION. HEAT AND COLD.

EVERYONE knows the physical phenomenon of resonance. If near a series of tuning forks one produces a tone on a piano or another musical instrument, those forks that have the same frequency as the sounding instrument will begin to vibrate and the intensity of the tone will be augmented. This is the phenomenon of resonance, and such sound-augmenting apparatuses are called resonators. Every apparatus and every organism will react only to those energies of the external world for which it has resonators capable of responding to the particular vibrations. A radio is a resonance instrument attuned to particular wavelengths — namely, those emitted by the broadcasting stations.

Man is a receiving apparatus whose resonators are the sense organs [Fig. 330]. He has two kinds of resonators:

I. *Resonators for Near or Contact Reception* [Fig. 331].

1. Pain apparatuses register contacts that penetrate the horn layer (a).
2. Touch apparatuses register contacts on the surface of the skin (b and c).
3. Pressure apparatuses register contacts that depress the surface layer of the skin (d).
4. Air-current mechanisms register the flow of the air over the surface of the body [Fig. 332].
5. Tickle apparatuses register certain types of contact that are important for the propagation of the species, since they tend to excite sexual desire [Fig. 331 (f)].
6. Traction apparatuses register any pull or push which raises or moves the skin (h).

II. *Resonators for Distant Reception* [Fig. 332].

7. Taste apparatuses register the molecular movements of fluids at the frontier of the body.
8. Olfactory apparatuses report the molecular movements of gases in the neighbourhood of the body.
9. Sound apparatuses register undulatory movements of the air.
10. Temperature (hot and cold) mechanisms react to changes of temperature.
11. Optic apparatuses register light stimuli.

Pain. Every one of us has known pain, but no one knows the mechanism by means of which pain arises. It has been conjectured that pain is due to injury of free nerve endings in the epithelium. For this reason weak stimuli never produce pains. To produce a pain one must employ a very much greater energy

than is necessary to arouse a sensation. There appear to be no special receptors for pain. There are, however, special nerve tracts for pain, which pass upwards in the spinal cord in close connection with the temperature tracts [Fig. 278 (4)]. They probably arise from the free nerve endings that are located among the cells of the corium just beneath the horny covering of the skin [Fig. 331 (a)], for where there are no nerve endings no pain is felt. The points on the skin that respond to adequate stimuli with a sense of pain are known as pain spots. The density of the pain spots varies in different skin areas. In the mucous membrane of the cheek there are rather large areas within which no pain spots can be detected. The different types of pains—burning, cutting, stabbing, gnawing, boring, etc.—are probably produced by a simultaneous stimulation of other sensory mechanisms. What we call pain is not a simple, but rather a mixed sensation consisting of pain, pressure, elevated temperature, etc.; it is not a single tone, but a composition—an evil melody.

Touching, Stroking, Tickling. Some of the nerves of the skin do not terminate freely, but at the base of large bulbous cells [Fig. 331 (b) and (c)]. By means of these mechanisms we perceive contacts between the skin and other objects, as well as stroking movements along the skin. Somewhat deeper than these cells lie spheres of greater circumference, upon the surface of which nerves ramify (f). These are receptors for the tickling sensation. A tickling sensation is a peculiar state of excitation, varying between pleasure and discomfort, in a stimulated nerve. It is a kind of questionable, ambivalent pleasure; one yearns for it to increase, yet at the same time feels that it would be more comfortable if it would cease. The tickling

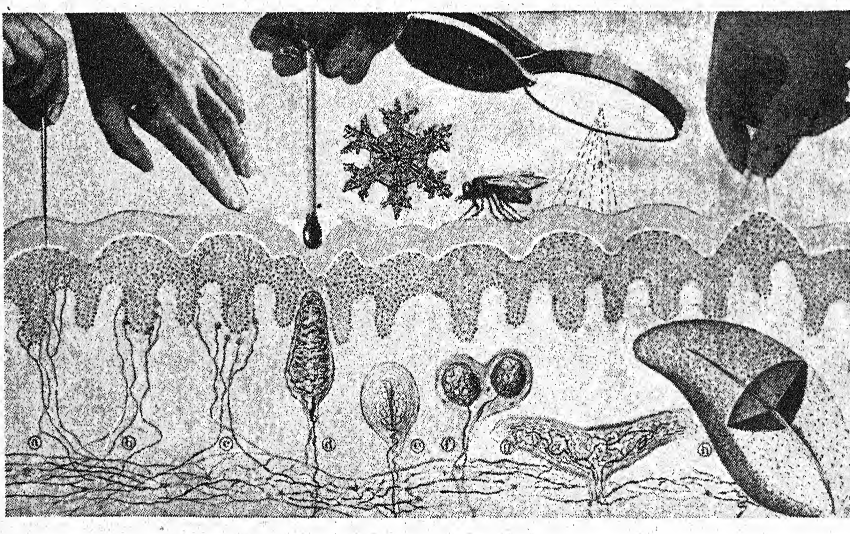


FIG. 331. *Sensory organs of the skin, chiefly for the perception of stimuli that act upon the skin directly. They are nerve cells for perceiving (a) pain, (b) touch, (c) stroking, (d) pressure, (e) cold, (f) tickling, (g) heat, (h) distortion.*

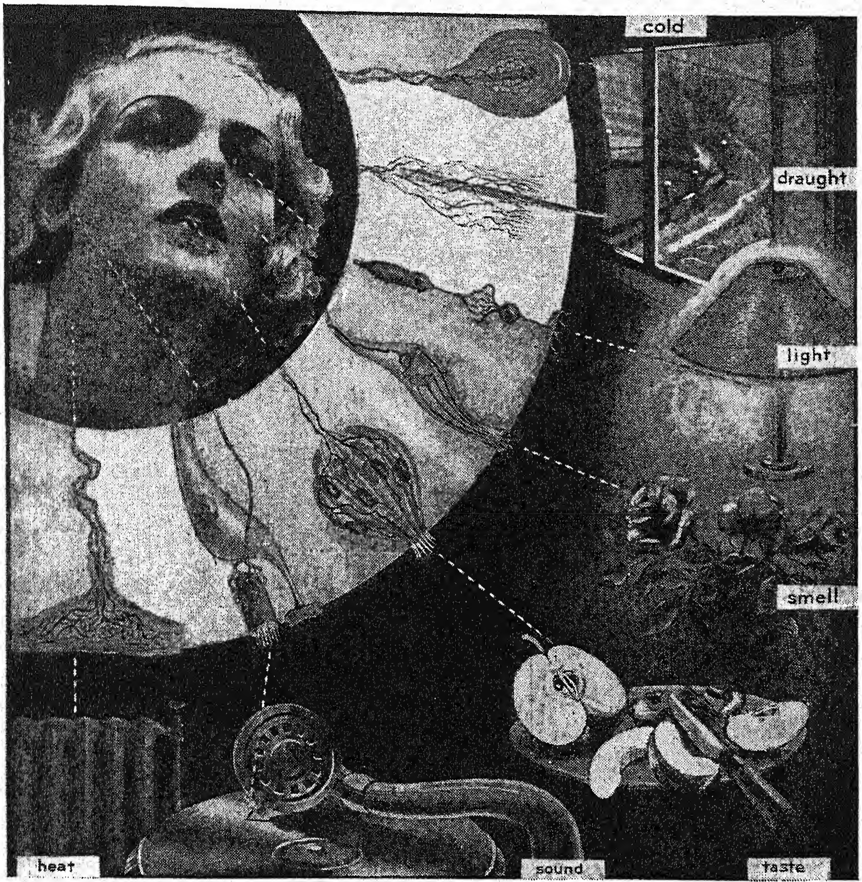


FIG. 332. *Sensory organs of the head, for the perception of stimuli of distant origin.*

sensation has profoundly intimate, and to a large extent as yet unexplained, relations with the drives, acts, and functions that serve to maintain the species. Eating, laughing, caresses between mother and child, the suckling of the child at the mother's breast, the kiss, and the sex act are all connected with tickling sensations.

Tactile Impressions. Immediately beneath the cells of the epidermis lie the most elevated of all the sensory apparatuses, the tactile corpuscles, which exhibit a remarkable similarity to the spring contacts used in electrical mechanisms [Fig. 331 (d) and Figs. 333 and 334]. Approximately a dozen cells are arranged horizontally within a capsule and are superimposed one on another, like the small bars of chocolate in the automatic vending machines in railway stations; among them terminate the branches of the sensory nerve fibres. When pressure is exerted upon the tactile corpuscle, contact is made between the elements of the corpuscle, the circuit is closed, and a nerve current travels to the brain.

where it "rings" the appropriate cortical cell [Fig. 334]. The number of such "push-buttons" found in different skin areas varies greatly. On the back each square millimetre of skin contains 1 to 2 tactile corpuscles, while an area of equal size on a fingertip contains 25 corpuscles. The greater the number of corpuscles in a given area, the more delicate is the ability to differentiate tactile impressions. The tip of the tongue has the finest tactile sense, not only because it has many tactile corpuscles, but also owing to the circumstance that only a thin mucous membrane separates them from the external world. The tip of the tongue can still distinguish the two points of a pair of compasses even when they are only $\frac{1}{25}$ inch apart. On the lips the compass points must be $\frac{1}{6}$ inch apart to be differentiated, while on the nose this distance increases to $\frac{1}{4}$ inch, on the forehead to $1\frac{1}{5}$ inches, and on the back to $2\frac{3}{5}$ inches [Fig. 335]. If the points of a pair of compasses $\frac{2}{5}$ inch apart are moved up along the arm away from the fingers, one has a feeling that the points of the compasses are moving away from each other, because the upper part of the arm is not accustomed to perceiving two tactile stimuli that are so close together. However, if the points are moved very gently along the skin, one succumbs to the illusion that they are coming closer together.

The Braille Alphabet for the Blind. Six tactile stimuli are the most that one can differentiate simultaneously. For this reason the groups of dots in the Braille alpha-

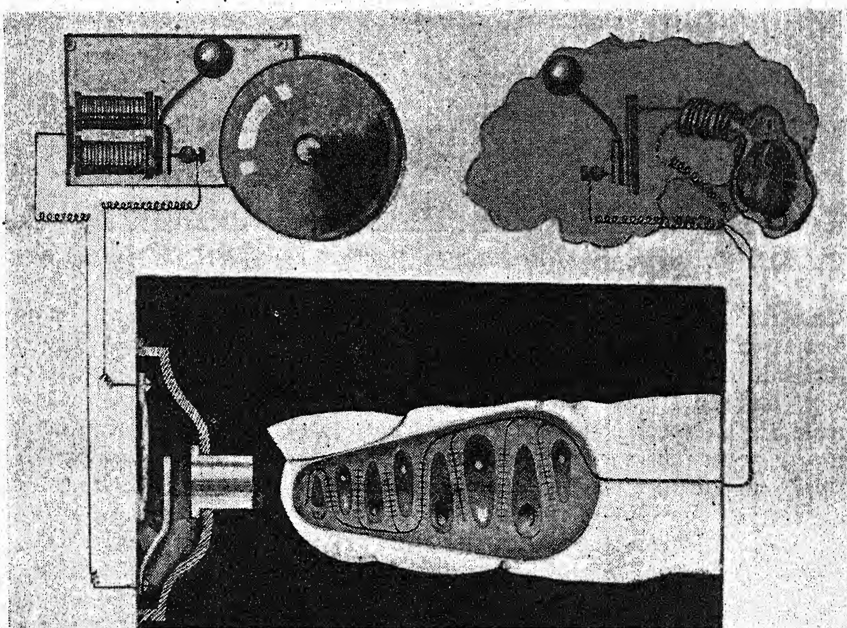


FIG. 333. *What happens when we press a bell. In our skin are touch corpuscles which operate like the spring contacts of an electric bell. The finger above is shown with only one of its many touch corpuscles, highly enlarged (See Fig. 334).*

bet never contain more than six surface elevations. Since the sensation of touch is recorded by a mechanically functioning pressure apparatus, it takes a relatively long time before the conduction current appears. Thus, all animals that orient themselves by means of tactile corpuscles slink along slowly, while animals such as the ungulates that have other means of orientation execute rapid movements.

A tactile sensation is a differential sensation. When the hand is immersed in mercury the pressure, although it is strong, is not felt, because all the touch corpuscles are put under pressure at the same time. Only at a line along the surface where the immersed and non-immersed parts of the skin meet does one experience a sense of pressure.

Record Achievements of the Tactile Sense. Like every other faculty the sense of touch is also influenced by training and talent. The finger-tips have become sensitive for tactile stimuli because we use them to touch. The degree of development of the tactile sense varies in different individuals; indeed, there are even " touch geniuses," like the man who was engaged at a high salary because he was able to distinguish counterfeit coins by touch while examining them at great speed. The great masters of the tactile sense are blind people, and among the latter the most expert are those who are deaf as well. Because of this circumstance they are not distracted by any other sensory impressions, but react only to tactile stimuli. The accomplishments of the blind deaf-

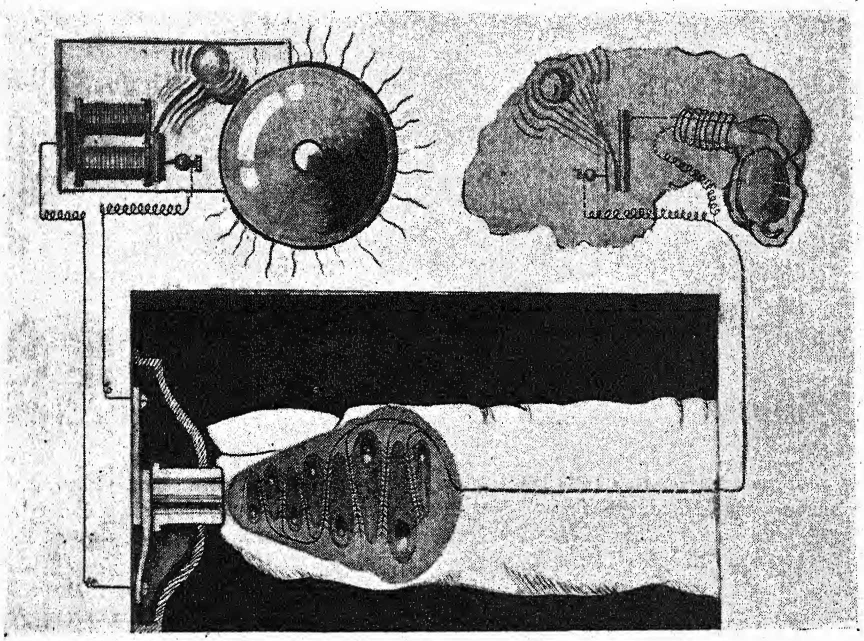


FIG. 334. *When our finger presses the button, two circuits are set in action—the electric circuit of the bell and the nerve circuit of the body. Thus, pressure of the finger rings the bell and also sends a touch "message" to the brain.*

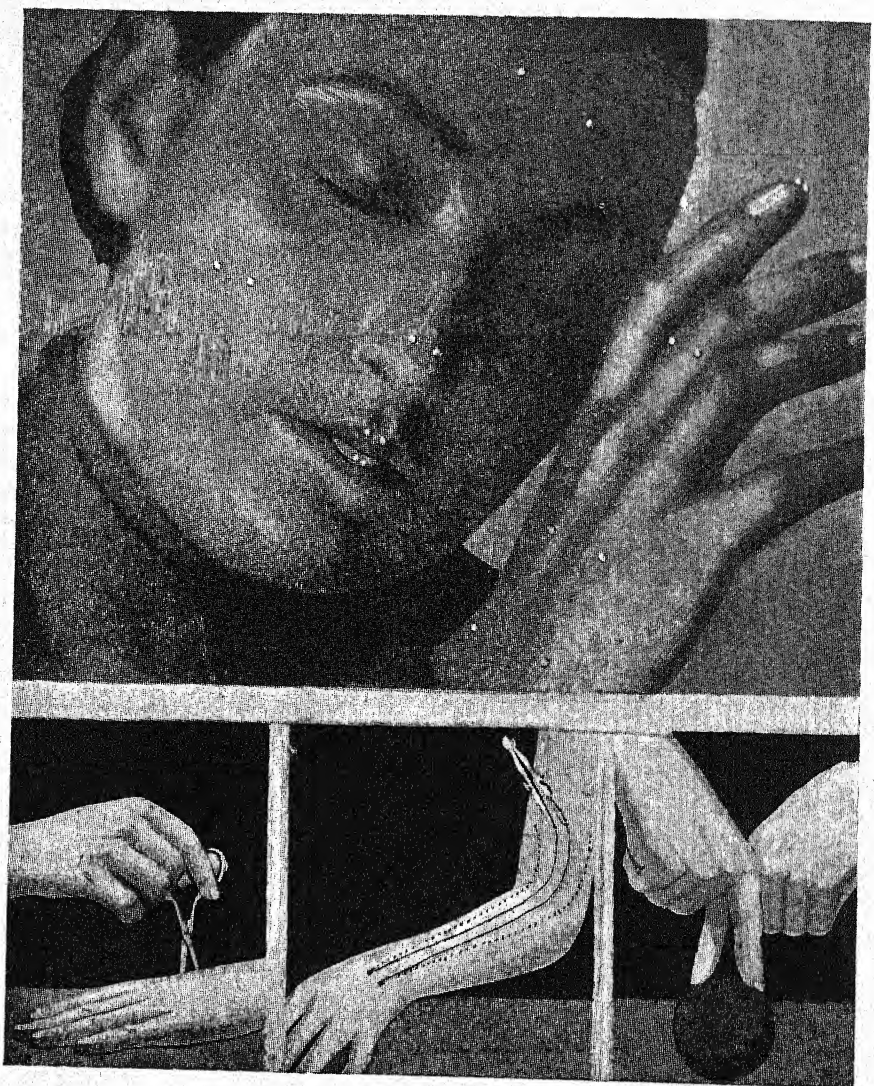


FIG. 335.—*Accomplishments and failures of the sense of touch. Delicacy of touch depends upon the number and degree of dispersion of the touch corpuscles. Thus, two compass points are perceived by the tongue as separate points when they are $\frac{1}{25}$ in. apart, but by other areas at the following distances: fingertips, $\frac{1}{12}$ in.; lips, $\frac{1}{6}$ in.; tip of the nose, $\frac{1}{4}$ in.; cheek, $\frac{7}{16}$ in.; back of the hand, $1\frac{3}{16}$ in.; forehead, $1\frac{1}{5}$ in.; forearm $1\frac{9}{16}$ in.; back, $2\frac{3}{5}$ in. The lower pictures show three instances in which the sense of touch is deceived. (Left) Two scissor points $\frac{2}{5}$ in. apart are felt on the back of the hand as a single point. (Centre) Two compass points drawn upwards in parallel lines along the arm appear to move farther apart (Page 486). (Right) A ball touched with two crossed index fingers feels like two objects, because we are not accustomed to the stimulation of these two sides of the forefingers simultaneously by a single body.*

mute Helen Keller, who learned to "speak" by means of tactile stimulation of her hands, and was able to follow lectures with the assistance of an interpreter, have become famous. Similar is the case of the deaf and blind Miss Huggins who deciphered newspaper headlines with her fingertips.

"There's a Draught . . ." The roots of the hairs are surrounded by a network of nerve fibres that terminate freely around them [Fig. 326 (N) and Fig. 332]. If air in motion passes over the hairy parts of the skin, the hairs are depressed like sheaves of corn in a wind. We feel the pull on the roots of the hairs and say: "There's a draught. . . ." We feel this pull most on those areas of the skin that are covered by rows of delicate hairs—the back of the hand, the outer surfaces of the arms and the back. Many people have a hysterical fear of draughts. While it is true enough that draughts may lead to colds, especially when the skin has been overheated, yet the exaggerated fear of every draught with which children are "inoculated" in some fam[illegible]ies and by which they are domin[illegible]te[illegible] throughout life, almost like a [illegible]osis, is equally false.

Morbid [illegible]

It [illegible] constantly afraid [illegible] because one can [illegible]sing the body [illegible] is overheate[illegible]enefiting a [illegible]ome one o[illegible]als who a[illegible] beings [illegible]

Trac[illegible] Skin. [illegible] which [illegible] the co[illegible]

beautiful structures of the body [Fig. 315 (m)]. They consist of several dozen connective membranes arranged like the layers of an onion around a nerve rod. The spaces between these layers are filled with lymph [Fig. 331 (h)].

Changing Pressure

When the skin becomes distorted by pressure, the lymph-pressure changes, and consequently the pressure upon the nerve. These lamellar corpuscles transmit the sensations produced when the skin is subjected to traction and distortion. They are present not only in the skin but occasionally also in the capsules of the joints and muscles, in the peritoneum, and in the walls of the large blood vessels. Their total number is about 1,500.

Heat and Cold. Heat and co[illegible]l, unlike pain, are not percei[illegible] equally well in all parts of the bo[illegible] but only where the special mech[illegible] isms for hot and cold are stimul[illegible] While we are quite well informe[illegible] garding the eye, the recepto[illegible] short light waves, because owi[illegible] its size it is accessible to inv[illegible] tion, we know nothing as yet [illegible] the mechanics of the heat an[illegible] receptors. All we can say is th[illegible] vary in their structure [Fig. [illegible] and (g)] and are distributed o[illegible] skin with equal irregularit[illegible] abdominal aspect of the b[illegible] more heat receptors, while [illegible] has more cold receptors, be[illegible] unprotected back is suppo[illegible] form us regarding the degr[illegible] of the external environme[illegible] the abdominal surface of [illegible] which in the female is li[illegible] breeding side, is supposed [illegible]nd regulate the tempera[illegible] [illegible]st and the warmth of th[illegible]

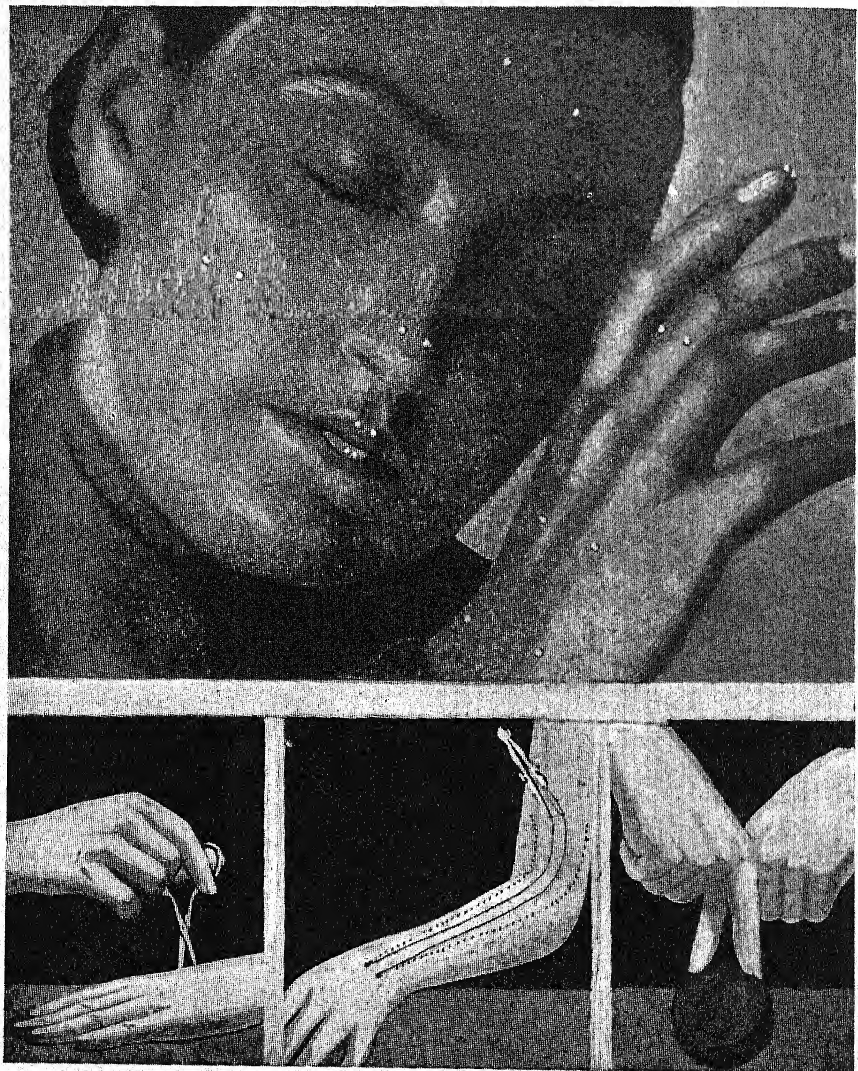


FIG. 335.—*Accomplishments and failures of the sense of touch. Delicacy of touch depends upon the number and degree of dispersion of the touch corpuscles. Thus, two compass points are perceived by the tongue as separate points when they are $\frac{1}{25}$ in. apart, but by other areas at the following distances: fingertips, $\frac{1}{12}$ in.; lips, $\frac{1}{6}$ in.; tip of the nose, $\frac{1}{4}$ in.; cheek, $\frac{7}{16}$ in.; back of the hand, $1\frac{3}{16}$ in.; forehead, $1\frac{1}{5}$ in.; forearm $1\frac{9}{16}$ in.; back, $2\frac{3}{5}$ in. The lower pictures show three instances in which the sense of touch is deceived. (Left) Two scissor points $\frac{2}{5}$ in. apart are felt on the back of the hand as a single point. (Centre) Two compass points drawn upwards in parallel lines along the arm appear to move farther apart (Page 486). (Right) A ball touched with two crossed index fingers feels like two objects, because we are not accustomed to the stimulation of these two sides of the forefingers simultaneously by a single body.*

mute Helen Keller, who learned to "speak" by means of tactile stimulation of her hands, and was able to follow lectures with the assistance of an interpreter, have become famous. Similar is the case of the deaf and blind Miss Huggins who deciphered newspaper headlines with her fingertips.

"There's a Draught . . ." The roots of the hairs are surrounded by a network of nerve fibres that terminate freely around them [Fig. 326 (N) and Fig. 332]. If air in motion passes over the hairy parts of the skin, the hairs are depressed like sheaves of corn in a wind. We feel the pull on the roots of the hairs and say: "There's a draught. . . ." We feel this pull most on those areas of the skin that are covered by rows of delicate hairs—the back of the hand, the outer surfaces of the arms and the back. Many people have a hysterical fear of draughts. While it is true enough that draughts may lead to colds, especially when the skin has been overheated, yet the exaggerated fear of every draught with which children are "inoculated" in some families and by which they are dominated throughout life, almost like a psychosis, is equally false.

Morbid Fears

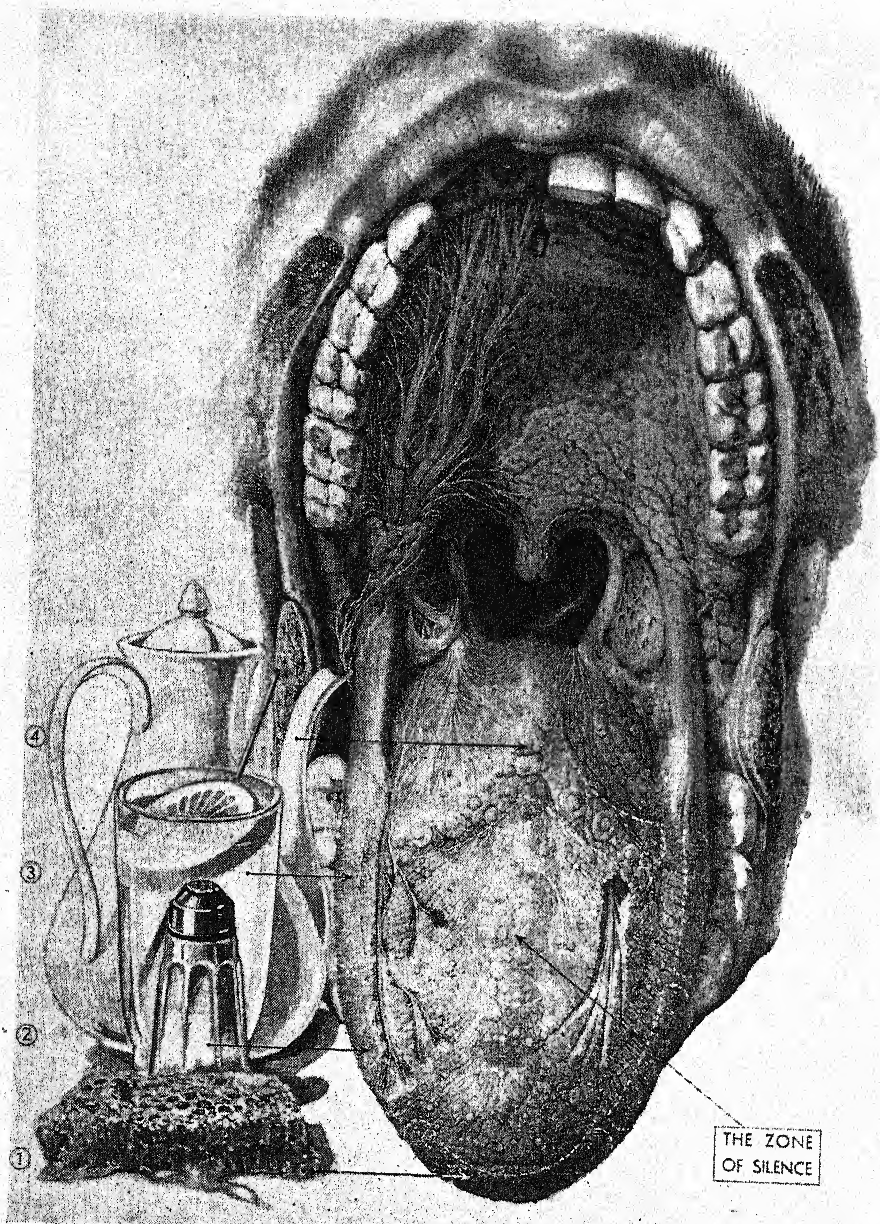
It is as if one were constantly afraid of cold water, just because one can catch a cold by immersing the body in cold water when it is overheated. One is certainly not benefiting a child by training it to become one of those unpleasant individuals who are a burden to their fellow beings because of this phobia.

Traction and Distortion of the Skin. The lamellar corpuscles, which are rather deeply situated in the corium, are among the most beautiful structures of the body [Fig. 315 (m)]. They consist of several dozen connective membranes arranged like the layers of an onion around a nerve rod. The spaces between these layers are filled with lymph [Fig. 331 (h)].

Changing Pressure

When the skin becomes distorted by pressure, the lymph-pressure changes, and consequently the pressure upon the nerve. These lamellar corpuscles transmit the sensations produced when the skin is subjected to traction and distortion. They are present not only in the skin but occasionally also in the capsules of the joints and muscles, in the peritoneum, and in the walls of the large blood vessels. Their total number is about 1,500.

Heat and Cold. Heat and cold, unlike pain, are not perceived equally well in all parts of the body, but only where the special mechanisms for hot and cold are stimulated. While we are quite well informed regarding the eye, the receptor for short light waves, because owing to its size it is accessible to investigation, we know nothing as yet about the mechanics of the heat and cold receptors. All we can say is that they vary in their structure [Fig. 331 (e) and (g)] and are distributed over the skin with equal irregularity. The abdominal aspect of the body has more heat receptors, while the back has more cold receptors, because the unprotected back is supposed to inform us regarding the degree of cold of the external environment, while the abdominal surface of the body, which in the female is likewise the breeding side, is supposed to control and regulate the temperature of the nest and the warmth of the offspring.



THE PRINCIPAL ORGAN OF TASTE

FIG. 336. *The tongue, with its four taste zones, for tasting substances which are (1) sweet, (2) salt, (3) sour, and (4) bitter. These zones are not sharply defined, but overlap. In the centre of the tongue is an area that has no sensory buds and consequently is incapable of tasting; this is the so-called "zone of silence."*

CHAPTER XXXVIII

Taste

TASTE AND SMELL. THE TASTE BUDS. THE PHYSICS OF TASTE. THE CHEMISTRY OF TASTE. THE TASTE ZONES OF THE TONGUE. CHANGES OF TASTE. SMELL IS THE "BETTER HALF" OF TASTE. A CUP OF COFFEE. EXPERIMENTS IN TASTING.

PRIMORDIAL organisms all lived in the water. In order to test the character of the water and to perceive their prey, aquatic animals possess receptors which are stimulated by the molecular and atomic groups (ions) that are dissolved in the water. These receptors are nerve mechanisms that are constructed like buds and are called sensory buds. They consist of groups of flat cells arranged like the layers of an onion skin. Within these enveloping cells are six or eight taste cells. At their deeper ends the latter are connected with nerve fibres that terminate in the buds. The capsule formed by the enveloping cells has a small opening on the surface through which protrude the very fine threads with which the taste cells terminate towards the surface [Fig. 337].

Taste and Smell

The perception by the nerves of molecular and ionic impacts in fluids is called taste; their perception when in a gaseous state is called smell. Taste and smell are sisters. Taste is the smelling of liquids, and smell is the tasting of gases.

The Taste Buds. Among aquatic animals taste buds are distributed over the entire body. Fishes also taste with their tail fins. Among land animals the taste buds have naturally retreated to the moist oral cavity, and in the highest terrestrial creatures they are restricted within the mouth to the tongue. Take a mirror and examine your tongue. Its surface is covered with fine wart-like eminences called papillæ, some of which are shaped like mushrooms.

The Tongue

The taste buds repose in invisibly small depressions in the walls of these papillæ [Fig. 337]. These mushroom-shaped, or fungiform, papillæ are distributed chiefly along the edges of the tongue opposite (1), (2) and (3) in Fig. 336. On the back of the tongue one finds still another type of papilla. These are the circumvallate papillæ, the largest and least numerous of the papillæ on the human tongue. The number present may range from seven to twelve, and they are arranged like a series of frontier forts in the form of a V with its tip directed towards the root of the tongue. Each of the circumvallate papillæ is an elevation of the mucous membrane and is surrounded by a trench (4). The number of taste buds varies greatly, depending on the taste needs of the particular animal species. The whale, which swallows unchewed whole shoals of small fish, has few

or no taste buds. Man is a moderate taster, possessing 3,000 buds. A pig is more particular in its tastes, having 5,500 buds, a cow has 35,000, and an antelope 50,000 taste buds. In any zoo one can confirm the fact that while man is the most cultivated, he is by no means the most sensitive, taster.

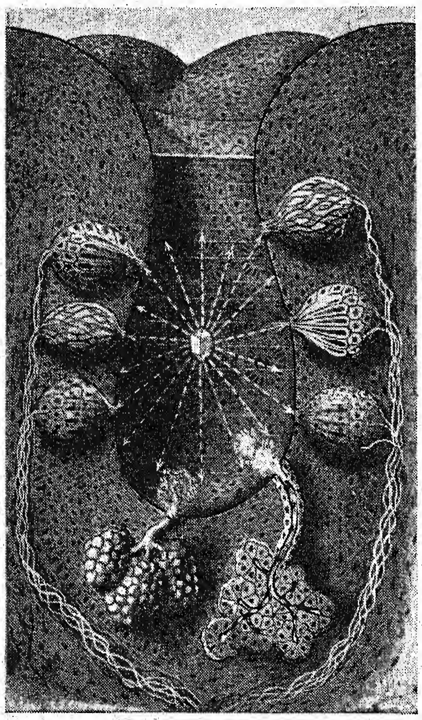


FIG. 337. *A view into one of the many taste pits of the human tongue. Taste is the perception of molecular impact in fluids. The molecules which the crystal hurls forth strike against the hairs of the sensory buds and produce a reaction in them, perhaps in the nature of an electrical current. Below are mucous glands.*

The Physics of Taste. More than two thousand years ago the Greek natural philosopher Democritus made the statement that the taste of foods depends on the kinds of atoms which they hurl forth. Even today we do not know very much more than Democritus. Yet everything more that we do know confirms the remarkable conjecture of the founder of the atomic theory. Only substances in solution, where the atoms move about very freely, can be tasted. A glass ball has no taste. Everything that accelerates the motion of the atoms intensifies taste; everything that inhibits atomic movement weakens taste. The taste of the small and consequently very mobile atomic groups of the salts is perceived most rapidly, one third of a second after they have been placed upon the tongue. The taste of bitter substances, which are almost always of high molecular weight, is first perceived after one second. Heat accelerates molecular motion and strengthens taste. When hot, wine has a sourer taste, and hot coffee has a bitterer taste than cold coffee.

Hot Food and Cold

Meat which tasted quite delicious when it was eaten hot at noon lacks all taste when eaten cold in the evening, so that we use mustard, pickles, or horse-radish to spice it. Salt pork is saltier when it is warm. Ice-cold foods require twice as much sweetening as warm ones. If ice-cream is allowed to melt on a plate at room temperature, it becomes so sweet that it can hardly be eaten. In sanatoria patients who must put on weight are given cold sweetened drinks and desserts in abundance, because in this way they can accept large quantities of cream and sugar without rebelling against them.

Watery fluids in which the atoms move easily and rapidly have a sharp taste. If the fluid is rendered

viscid, the motion of the atoms is inhibited and the food has a milder taste. Cognac is sharp on the tongue, while the viscid liqueurs have a milder taste. We add milk to coffee in order to reduce its bitter taste. If a cook finds that one of her dishes is too sharp, or if a doctor wants to make the bad taste of a medicine somewhat milder, they add colloids such as egg-white, milk, gelatine, or syrup as taste correctives.

The Chemistry of Taste. The taste buds register three or four different sensations: sweet, saline, bitter, and perhaps also sour, but the latter is possibly a sensation compounded of the other three.

An Unrevealed Law

Scientific investigation has left no doubt that the stimulating effect of any foodstuff on the taste nerves is related to its chemical constitution. Thus a sour taste is determined by the presence of hydrogen (H) ions, an alkaline taste by hydroxide (OH) ions. Many amino acids, the constituent elements of protein, have a sweet taste; on the other hand, the polypeptides produced by a combination of these amino acids have a bitter taste. Most alcohols and sugars have a sweet taste, while the compounds formed by combining these substances with metals are bitter. As yet we have no comprehension of the law that determines what the taste of any given substance should be.

Varying Impressions

The Taste Zones of the Tongue. The tongue is not equally sensitive at all points to all four tastes [Fig. 336]. The back of the tongue is more sensitive to bitter (4), the sides react more easily to sour (3) and salt (2) substances, while the tip perceives a sweet taste (1). Differences may even be detected among the papillæ themselves. Thus a mixture of quinine and sugar applied to one circumvallate papilla produces a sweet taste, while with an adjacent papilla a bitter taste may predominate.

Sweet and Sour

Changes of Taste. Almost all our foods are composed of mixed substances, and consequently stimulate not one but several, often even all four kinds of taste mechanisms, thus producing the mixed sensations of taste. A lemon has a bitter as well as a sour taste; an apple is sour and sweet at the same time. On the front part of the tongue alum produces a sour taste, while on the back it creates a sweetish taste. By paralysing or stimulating certain groups of taste buds, the accustomed taste of a substance can be materially changed. After washing one's mouth with a solution of potassium permanganate, a cigarette will have a sweet and not a bitter taste. If one adds a pinch of salt to some sugared water, the sweet taste becomes more pronounced.

Mixed Sensations

Taste differs from other physical sensations in that it is not a pure sensory stimulation like vision or hearing, but rather a mixed sensation composed of gustatory, tactile, pressure, cold, heat, and olfactory impressions. There is no pure taste because the tongue perceives not only a sweet or a saline sensation, but also the weight, fluidity, roughness or smoothness, mildness or sharpness, temperature, viscidity, and volatility of food. Lemonade

has both a sweet and a sour taste, but in addition it may be also cold or lukewarm. Because of the carbon dioxide contained in them, aerated fluids stimulate the oral mucous membrane almost as if it were being tickled. We like tea as hot as possible without burning the mouth. At the same time the tannic acid in the tea corrodes the tongue, while the milk covers it like a soothing salve. Biscuit crumbles, a pudding is sticky, chocolate melts, a strawberry produces a furry sensation. From the combination of these many sensations results that which we describe as the taste of food.

Interwoven Senses

Smell is the "Better Half" of Taste. Next to the taste buds the olfactory apparatus plays the largest part in producing the taste sensation. The taste process may be compared with a song, where taste represents the vocal part and smell the piano accompaniment. Both are interwoven to such an extent that without the piano the vocal part sounds not only thin and empty, but actually deserted. At least half of what we describe as taste is not taste at all, but smell. Coffee, tea, tobacco, wine, apples, oranges, lemons, vanilla, raspberry, and cocoa stimulate olfactory rather than gustatory mechanisms.

Importance of Aroma

A Cup of Coffee. In Figure 338 the attempt has been made to represent the act of tasting coffee, although a true presentation of this subject would actually require a succession of pictures, a film strip, and not a single picture. First, phase I takes place; we smell the odour arising from the cup (A). A genuine coffee-drinker does not gulp down his coffee like water, but first enjoys the aroma, just as a professional cognac-taster does not take the cognac into his mouth, but pours some of it on hot water and judges it by the odour. Similarly, a connoisseur of wine does not drink it immediately, but first smells the bouquet.

Warm Fluids

Then follows phase II, sipping the coffee. This too is not a simple process of tasting. First of all we want our coffee to be hot, so as to produce a pleasant feeling of warmth in the mouth. Then we feel the fluidity of the coffee. Entirely apart from any other qualities, coffee should not be too thin, but should possess a certain consistency so as not to flow too rapidly and too superficially over the tongue, since it contains the bitter substances that require a long stay and deep penetration in the depressions surrounding the circumvallate papillæ on the back of the tongue.

Prelude to Taste

We are not yet quite ready to notice the taste of the coffee, since we first feel the tannic acid contained in it, which passes over the tongue like a velvet brush. Now we taste the beverage—at first its sweetness, if it has been sugared, then the delicately steamed acid which is perceived by the edge of the tongue, and finally the bitter substances obtained by roasting that produce the characteristic coffee taste. All this together, however, does not yet give the actual taste of coffee, which we do not perceive until phase III. After swallowing the coffee we exhale deeply since respiration is momentarily suspen-

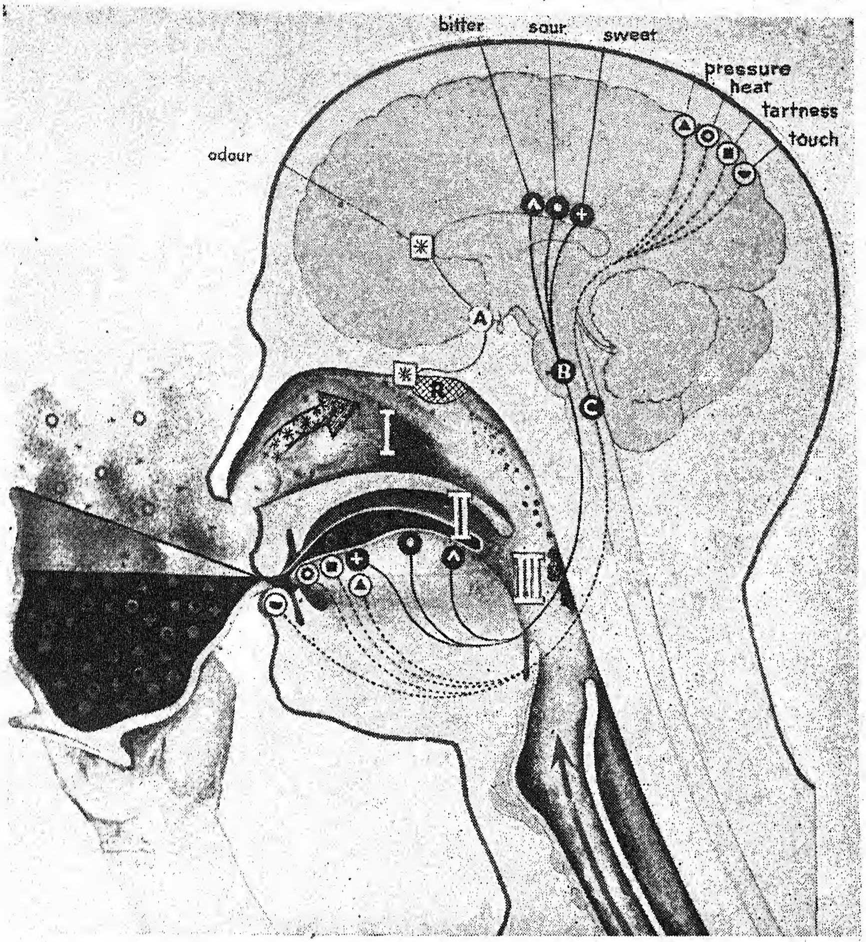


FIG. 338. *The tasting of a mouthful of coffee, simple enough as it may appear to us, is really a highly complex process, which takes place in three phases. In this illustration (R) represents the olfactory area of the pharynx; (A) is the olfactory nerve tract; (B) the nerve tract of taste; (C) the sensory nerve tract. The qualities of sweetness, warmth, etc., in the coffee are represented by symbols. Phase (I) is olfactory, involving only the aroma of the coffee; as it enters the nose from the external air. In phase (II)—sipping—the warmth and fluidity and the acid, sweet and bitter content of the coffee are detected by the mouth and tongue. Phase (III), the completion of the taste process, is once more olfactory; air from the lungs carries a stream of coffee vapour from the pharynx to the olfactory area of the nose.*

ded during swallowing. The expelled air is pressed against the wall of the pharynx as if by a gust of wind. The pharyngeal wall is bathed by a stream of coffee (near figure III), and from the coffee-moistened pharyngeal wall the current of air pushed up from the lungs carries a cloud of coffee vapour up into the nose. Not until all this has hap-

FIG. 339. *Red wine or black coffee? After eliminating vision and the sense of smell, by covering the eyes and closing the nose, it is impossible to tell the difference between wine and cold coffee, or between apples and potatoes.*

pened and we are, so to say, enveloped in a cloud of the imbibed beverage, not until then do we express our satisfaction by saying: "How good this coffee tastes!" Smell is the better half of taste. A great many people deny the truth of this fact, yet it can easily be demonstrated by the following simple experiment [Fig. 339]. Close someone's nose with a clothes peg or cotton-wool and blindfold him. Then give him two identical glasses, the first containing red wine, the second unsweetened black coffee of approximately the same consistency and temperature. Now, after tasting the contents of each glass, let him say which contains coffee and which wine.

Experiments in Taste

You should repeat this experiment several times. Then try the experiment with an apple and a raw potato, a tomato and an orange, with raspberry water and sweetened milk. In such experiments one must take care that the person who is being tested does not differentiate the two substances by means of certain physical characteristics or properties—for example, variations of fluidity, softness, and the like. Innumerable wagers have been lost in such experiments, yet every head cold shows that the taste of food disappears with the loss of the sense of smell, and that under such circumstances all foods taste alike. Only the accessory sensations of the gustatory process, the tactile sensations, remain, so that the sufferer complains that all his food tastes like cardboard.

CHAPTER XXXIX

Smell

MAN A VISUAL ANIMAL. THE NASAL TURBINATES. THE PHYSICS AND CHEMISTRY OF SMELL. ODOUR-CARRIERS (OSMOPHORES). THE SIX TYPES OF ODOURS. SMELL IS A MIXED SENSATION. PHYSICAL CHARACTERISTICS OF ODOROUS SUBSTANCES. OLFACTORY TALENT AND ACCOMPLISHMENTS. THE NOSE KISS.

As a result of the assumption of an upright position by man and the removal of the head from near the ground, man's olfactory sense has deteriorated and he has become a "visual" animal. In zoology animals can be divided into two groups—visual and olfactory animals. Ants, bees, dogs, and almost all domestic animals are olfactory animals. The ant orients itself exclusively by means of its olfactory sense; it loves and hates with its olfactory antennæ. An ant with a friendly odour is loved, one with a hostile smell is killed. If an ant is covered with a hostile odour, it will be killed by its comrades. Similarly, a mother rabbit will kill one of her young, which she had defended five minutes earlier at the peril of her life, if it is perfumed with the odour of an enemy.

Smell and Emotion

Should it be desired to have two groups of bees live in harmony, they are shaken together in a box until friend and foe can no longer be differentiated. A dog lives, feels, loves, and hates exclusively by means of its sense of smell. A man who has taken a walk with his dog tells what he *saw* upon his return. If the dog could talk, it would not relate the same experiences, but would report where and what it *smelled* during the walk. If a dog's olfactory nerves are severed, it loses all its canine virtues despite its beautiful, faithful eyes. The dog is no longer alert, vigilant, or obedient, no longer exhibits any attachment or affection, and is in general useless, since its nose is the portal for its experiences and reactions.

Scent in Man and Dog

The Nasal Turbinates. The human nose is divided into three storeys by the turbinate bones which project from the lateral walls [Fig. 341 (b)]. The organ of smell, the olfactory mucous membrane, is located above the superior turbinate. It is here, in the area designated by (R) in Figure 338, that olfactory stimuli are perceived. The human nose may be compared to a house in which the organ of smell has been removed to the attic. The olfactory area is small. On each side it is as large as a fingernail. The nasal cavity of the dog, however, has not three turbinates only, but an entire turbinate labyrinth covered almost completely by an olfactory membrane. If a dog's olfactory mem-

FIG. 340. *Man is an "eye" animal, while a dog is a "nose" animal, dependent upon its olfactory sense for most of its physical and emotional impressions. Accordingly, while the olfactory area in man occupies one-twentieth of the medial surface of the brain, in a dog it covers more than one-third of the brain's entire inner wall.*

brane were spread out flat, it would cover an area equal to more than half that of the animal's skin [Fig. 341].

These same relations obtain in the brain. In a dog's brain the olfactory sphere occupies almost one-half the wall of the cerebrum, while in a human brain this is reduced to one-twentieth. Man has other things to think about than to occupy himself with olfactory impressions. In contrast to his dog, man has become a " visual " animal and, owing to his speech, a creature with a developed sense of hearing as well [Fig. 340].

The Olfactory Mucous Membrane. The olfactory mucous membrane can easily be recognized with the naked eye by its brownish-yellow colour. This colour arises from the presence of a brown pigment, which must somehow be related to the olfactory process since it is present in the olfactory apparatuses of most animals. In animals with a strongly developed sense of smell, such as dogs, deer, and cattle, the entrances to the olfactory organ, the nasal orifices, are deeply pigmented. In

every animal group individuals that lack pigment are poorer smellers than their darker comrades. In Virginia white hogs frequently die because they are unable to distinguish Lachnanthes, a poisonous root which grows there, from other plants. Similar cases are those of white rhinoceroses in Africa and white sheep in southern Italy that eat poisonous grass.

Sensory Hairs

The olfactory membrane is a simply constructed mucous membrane, containing goblet-shaped nerve cells surrounded by nerve fibres, which is kept moist by mucous glands. The olfactory cells present small craters to the outer world, through which delicate sensory hairs project into the air-filled nasal cavity [Fig. 343].

The Physics of Smell. Everything appears clear and simple—if it were only so. However, the tips of the olfactory antennæ do not extend directly into the air, but are embedded in a lipoid layer which covers the olfactory membrane. If the nose becomes dry so that the ends of the olfactory cells are uncovered, the ability to smell disappears. Every hunter knows that a hunting dog accomplishes less in the dry noon air, and police dogs are put on a trail during the humid morning and evening hours.

Sniffing an Odour

In ordinary respiration the stream of air never passes beyond the superior turbinate, so that it does not come into contact with the olfactory area. If one wants to smell a flower or a fruit one sniffs—that is, the nostrils are dilated and the direction of the anterior part of the nasal chamber is altered, so that the stream of air is directed upwards towards the olfactory area.

The Chemistry of Smell. Since the hairs of the olfactory cells are not exposed but are covered by a lipoid layer, it seems probable that the olfactory process is not a simple physical one. The substance that is smelled must first dissolve in the fatty layer and be dispersed in it before it reaches the olfactory hairs. This may explain why a relatively long time elapses between the entry of the odorous air and the perception of the olfactory sensation. It also explains the fact that the odorous substances are either themselves volatile, "ethereal" oils such as the odorous substances of flowers or plant resins, or are brought to us

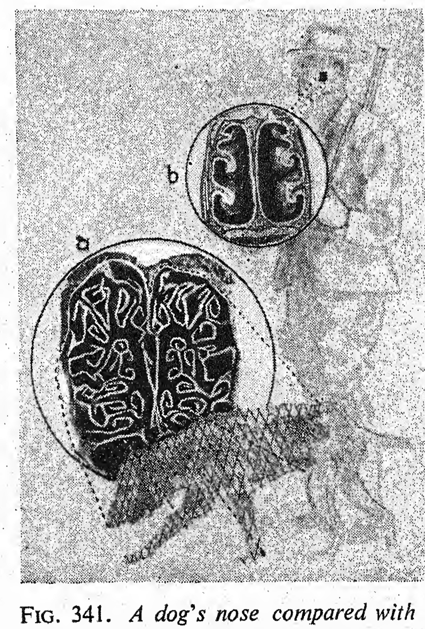


FIG. 341. *A dog's nose compared with a human nose. The olfactory area of the nose in man is about as large as a postage stamp, while that of a dog, if spread out, would cover more than half the area of its skin. It is also more elaborate.*

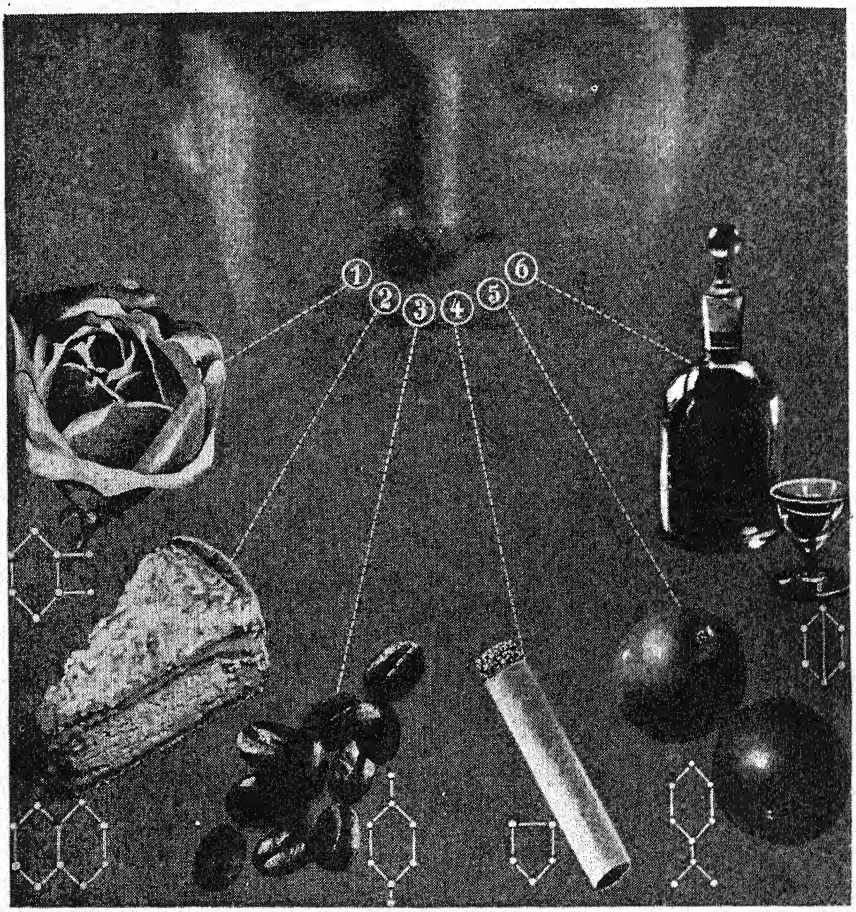


FIG. 342. *The six most important kinds of odours, with diagrams of their chemical formulæ. They are: (1) flowery odours; (2) putrescent odours; (3) and (4) aromas of burning and roasting; (5) spicy, or fruity, odours; (6) ethereal odours. Odoriferous substances belong to a group of chemical compounds of which the fundamental constituent is the formula of benzol. The type of odour is determined by the position of the atomic group of the substance. Thus all odours have an entirely chemical basis.*

in oily vehicles—for example, the aromatic substances of coffee, tea, cocoa—or are themselves oil solvents, such as benzine, turpentine, alcohol, ether, chloroform, acetone, and the like.

The olfactory process apparently requires rapid chemical decomposition, for substances that cannot be broken down chemically, or not without difficulty—the elements, for example—are odourless. Iodine and sulphur have no odour; what we smell are their easily decomposed hydrogen compounds. Oxygen (O_2) is odourless, but ozone (O_3), which is formed during electrical discharges, has an odour, because it loses its

third atom of oxygen very easily.

Odour-Carriers (Osmophores). The odour of a substance is dependent on the presence of certain groups of atoms called odour-carriers, or osmophores. Such groups are the amino group NH_2, the nitro group NO_2, the hydroxyl group OH, etc. The osmophores themselves have no odour, but odours arise when the osmophores occupy certain positions in certain molecules. Most odorous substances possess large molecules and have therefore high vapour densities.

Six Types of Odours

The most important types of odorous substances have been represented in Figure 342. Next to the object one sees a diagram of the chemical formula which is characteristic for all substances in the particular class. The following types are differentiated:

Flowery (1): Violet, rose, mignonette, jasmine, lavender, lilac, heliotrope, thyme.

Putrescent (2): Cheese, rotten eggs, marsh odour, manure, decomposing corpses.

Burnt or roasted (3) and (4): Tobacco, coffee, wood, coal, paper.

Spicy (5): Apple, pear, lemon, orange, pineapple, melon, cucumber.

Ethereal (6): Alcohol, benzine, ether, chloroform, camphor, pine-needle extract.

"Smell Fatigue"

When the olfactory mucous membrane becomes fatigued, the ability to perceive different types of odours disappears according to a definite sequence, and after recuperation returns in the same sequence. When one can no longer smell tincture of iodine, because of fatigue, the odour of turpentine may still be faintly, and that of lavender quite strongly, perceptible. When the ability to smell returns after a cold, one is able to smell oil of cloves before one can smell the odour emanating from a roast, and the ability to detect both of these odours precedes the ability to perceive the smell of rubber.

Combined Odours

Smell is a Mixed Sensation. Olfactory impressions, like those of taste, are mixed sensations. In the first place, most odorous substances present several types of odours. Peppermint smells flowery as well as spicy; pine-needle extract contains spicy substances and ethereal oils. Secondly, the olfactory stimuli can act simultaneously on other kinds of nerve endings in the nasal mucous membrane. Peppermint acts not only on the olfactory nerve, but also on the temperature corpuscles. A pungent odour such as that of ammonia not only stimulates the olfactory nerve, but involves stimulation of the nerve endings of ordinary sensibility supplied by the fifth cerebral nerve as well.

Mercaptan and Musk

Physical Characteristics of Odorous Substances. The amount of odorous substance necessary to excite an olfactory sensation is extremely minute. Thus .01 milligram of mercaptan diffused in 230 cubic metres of air is still distinctly perceptible. In this case a litre of air would contain .00000004 milligrams of the substance and the amount actually in contact with the olfactory membrane would be even smaller. But let us disregard mercaptan, which has an extremely repulsive odour, and turn to animal musk.

Although its odour is only half as strong as that of mercaptan, animal musk is the strongest of all perfumes. Take a lump of sugar in your hand. A quantity of musk of equal size would suffice to perfume the fluid in thirty million wine bottles.

It is possible, however, to demonstrate the presence of even minute quantities of these odorous substances in air by physical means. The British scientist Tyndall showed that air containing a small amount of an odorous substance absorbed more radiant heat than did pure air. Air containing patchouli absorbed sunlight 32 times as strongly as pure air, while thyme increased the absorptive power 70 times.

Most odorous substances have large molecules so that they diffuse very slowly. This accounts for the fact that smells tend to hang about objects. If a twelve-year-old boy smokes a cigarette at noon, the odour which clings to his clothes or hair will betray him to his mother in the evening. The odour of musk cannot be removed from clothes, even after they have been washed and ironed three times. Odours cling more tenaciously to dark materials than to light ones; the sequence is black, blue, green, red, yellow, white.

Training the Sense of Smell

Some odorous substances, such as fatty acids, are very volatile. If someone on the ground floor of a house fries fish in rancid oil, all the tenants in the upstairs apartments suffer. An iodoform dressing can taint an entire apartment with its odour.

The Accomplishments of the Olfactory Sense. On account of its decreased use, the olfactory sense has become weakened in man, but it is by no means completely vestigial, as one often hears. On the contrary, it still possesses great possibilities of performance and is above all capable of development.

Diagnosis by Smell

When the olfactory sense is trained by constant use, its accomplishments are astounding. A beginner cannot work with odorous substances more than ten minutes at most, because the olfactory organ fatigues rapidly. Later this period can be increased to one hour. Blind persons use their sense of smell to a much greater extent than people who can see, and as a result of training are capable of astonishing performances. Many physicians are reputed to be able to smell certain diseases. When the mother of a sick child wanted to conduct a famous nineteenth-century physician into the sick-room he said: "Don't wake her." Then opening the door slightly, he sniffed the air and announced his diagnosis: "Scarlet fever!"

Olfactory Talent. There are born "smellers." In their books some travellers describe the odours of different countries, provinces, cities, and bazaars as precisely as if they were dealing not with olfactory but with visual perceptions. In almost every literature there are writers, as for instance Turgeniev, Huysmans, Jacobsen, Zola, and Baudelaire, who describe olfactory impressions or delineate olfactory pleasures with a precision that is incomprehensible to the average person. Zola's olfactory accomplishments were so extraordinary that he was examined scientifically. He described olfactory sensations as other people do

visual impressions; and Baudelaire enjoyed odours just as a musical person enjoys the music of Bach or Mozart.

The Nose Kiss. Modern Europeans and Americans greet one another by shaking hands, and if they are intimate, kisses may be exchanged. In early times people smelled one another. The kiss was unknown to early man. In Sanskrit the word for "kissing," *ghrâ,* means "to smell"; in Old Persian the word for "love" means "smell"; in classical Greek there was no word for "kiss"; and in the Maori tongue there is no expression for "I greet you" except the phrase "I smell you." Even today the Maoris still use the nose kiss as an expression of greeting. The Japanese regard a mouth kiss in public with such abhorrence that all kissing scenes must be removed from cinema films destined for the Far East. The nose kiss may be regarded as a relic of a time when man based his feelings of sympathy or antipathy for other human beings upon the olfactory sensations which they provoked in him.

In modern man the nose has lost its significance as an organ of social and physical orientation, these functions being exercised by the eye and the ear. Today the nose is incapable of fulfilling its function as an apparatus for orientation in the struggle for life. A person who travels by motor-car and aeroplane, and who moves about in the eye-ear world of the newspaper, the cinema, and the radio, can no longer orient himself by means of the slow-working nose. Instead the nose has acquired a previously non-existent function; it has become an organ for the enjoyment of sensory impressions. An animal uses sensory impressions, but it doesn't enjoy them. A cow chooses with its nose the plants that it eats, but it does not delight in the odours of flowers.

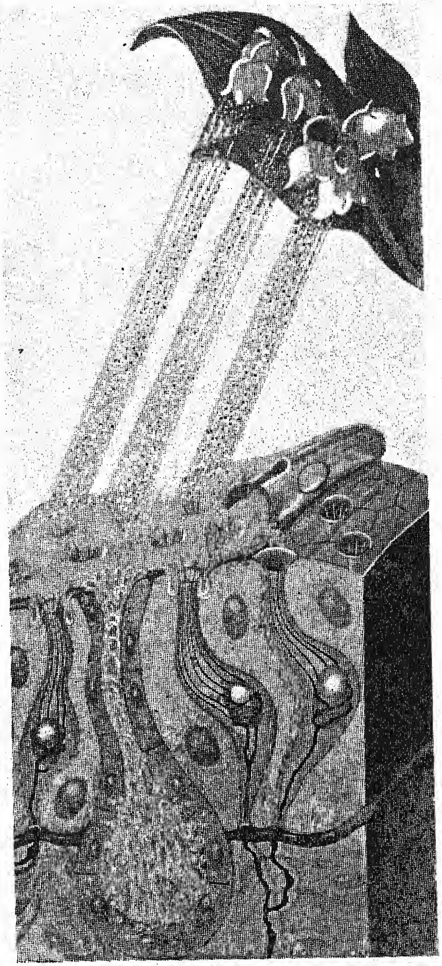
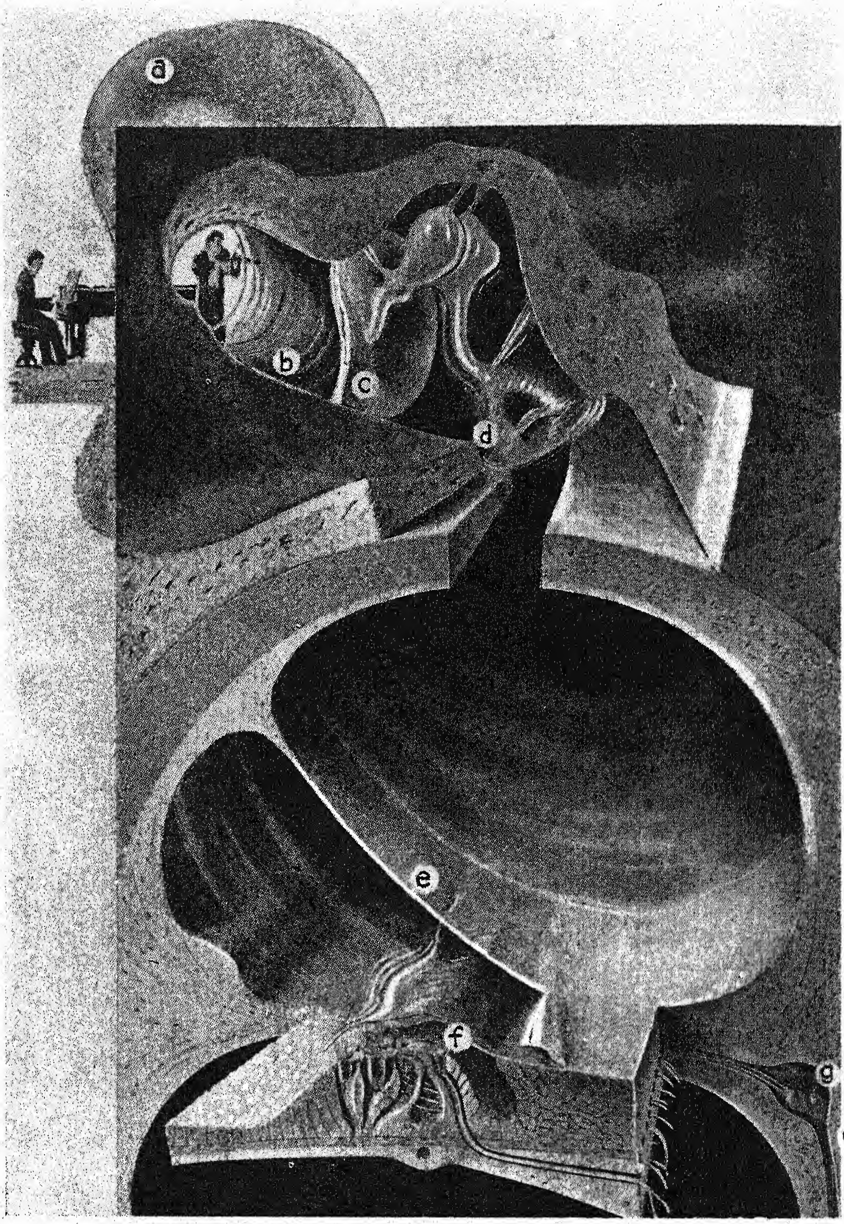


FIG. 343. *How man smells the perfume of a flower—a drawing of the marvellous apparatus (much enlarged) that enables us to detect odours. The flower emits molecules which impinge upon the sensory cells of the olfactory mucous membrane, producing nerve currents which travel to the brain. Glands keep the membrane moist.*



THE HUMAN EAR IN ACTION

Fig. 344. *A drawing of the inner structure of the ear, showing the mechanism through which sound vibrations are transmitted: (a) is the outer ear; (b) is the auditory canal; (c) eardrum; (d) auditory ossicles; (e) cochlear lymph; (f) sound membrane with auditory cells; (g) auditory nerves which convey the impulses to the brain.*

CHAPTER XL

The Ear

EQUILIBRATORY MECHANISM. THE SEMICIRCULAR CANALS. VERTIGO. SEASICKNESS. DEAF-MUTES. THE AUDITORY APPARATUS. THE DRUM. THE EUSTACHIAN TUBE. THE AUDITORY OSSICLES. THE COCHLEA. AN AUDITORY PIANO. THE KEYBOARD. THE TECTORIAL MEMBRANE. THE LYMPH. THE WINDOW MEMBRANES OF THE EAR.

SINCE the earth attracts everything in its neighbourhood by the powerful force of gravity, all locomoting organisms must be equipped with equilibratory mechanisms which will inform them of their spatial position in relation to the earth. Every moving structure which rises above the surface of the earth, whether it is a child's kite, an aeroplane, a medusa, a bird, or the body of a vertebrate travelling on its legs, must balance constantly, like a tight-rope walker, in order not to collapse or fall down.

The Equilibratory Mechanism of a Medusa. The organs of equilibrium of animals are among the most interesting technical structures of the organic world, and it is a fascinating chapter in the study of natural history to trace the increasing perfection of the various models in the course of animal evolution and to derive the structure of the human organs from simpler types.

Bells and Clappers

Figure 345 shows the pendulous "clapper" of a jellyfish (I) as an example of a simple equilibratory mechanism. Around the edge of a jellyfish, at the base of the tentacles, for example, or in the dome of the animal, there are arranged a row of *statocysts,* each consisting of a bell-like structure, lined with sensitive cells and containing a pendulous "clapper" made heavy by the deposition of limy salts in its end.

Balancing with Stones

When the jellyfish is tipped up at an angle by a wave or any other agency, the clapper within each statocyst swings over and strikes the sensory cells on one side of the bell. These cells send a nerve current to the depressed area, where the muscle cells contract, causing the jellyfish to right itself sufficiently to bring the clappers to a standstill and thus restoring equilibrium.

The Equilibratory Mechanism of a Lobster. In a lobster (II) the cavity of the organ of equilibrium communicates with the external world (a). In order to be able to grow, the lobster must discard its shell from time to time and acquire a new one. In the course of this moulting process both the internal membrane of the statocyst and the clappers are thrown off, so that the animal is helpless during this period. As clappers in the organs of equilibrium the lobster uses small stones which it collects after every moult

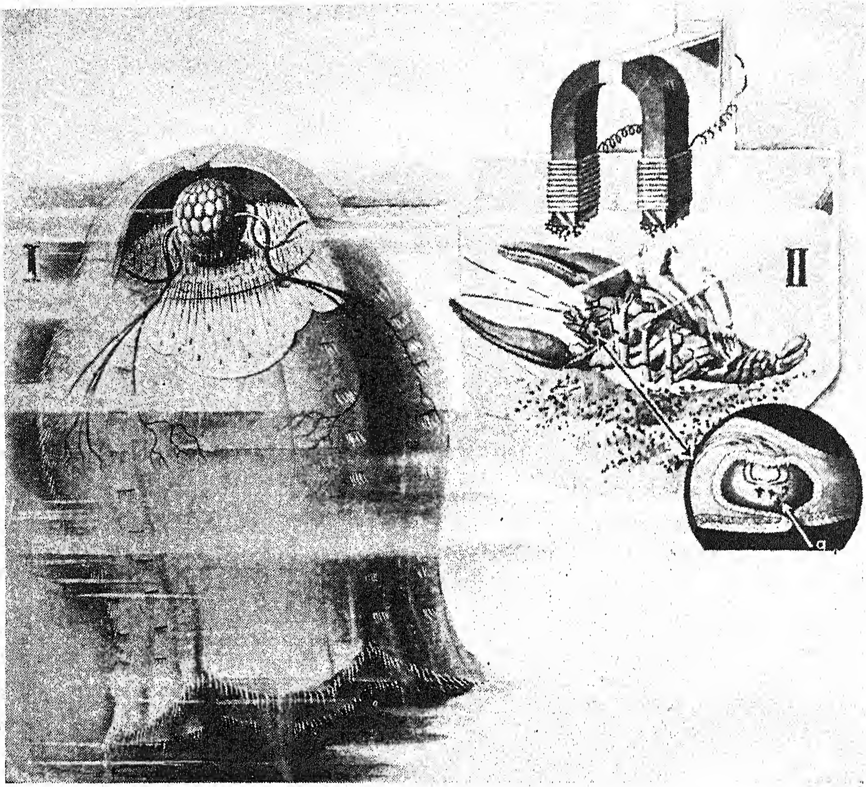


FIG. 345. *The equilibratory apparatus of lower animals: (I) a jellyfish is provided with an equilibratory sphere in a bell-shaped space; (II) a lobster into whose statocyst (a) iron filings have been introduced has, under a magnet, an inverted sense of space.*

and introduces into the statocysts. If a lobster is placed in an aquarium where there are no stones or sand, it is unable to replace its clappers and reels about as if it were drunk.

This fact forms the basis for an interesting experiment. A freshly moulted animal is placed in an aquarium containing iron filings. After the lobster has introduced the filings into the statocyst it is placed in a strong magnetic field. The magnet, acting upon the iron, counteracts the effect of gravity and produces abnormal forced movements of the lobster. It acts as if the magnet were the centre of the earth, and consequently moves in a spatial world whose centre of gravity is formed by the magnet. The lobster's view of the world is turned upside down (II).

The Human Equilibratory Mechanism. In man the two organs of equilibrium are located in the petrous portion of the temporal bone near the auditory mechanisms with which they are related embryologically [Fig. 353 (11)]. The human equilibratory mechanism functions on the same principle as that of ani-

mals, but it is a much later and consequently more complicated model of natural technology. In order to visualize the construction of the organ of equilibrium, one must think of two quite different structural forms: first, of balloon rigging, secondly, of a colonnade [Fig. 346]. The entire organ (c) is a sac, tensely filled with lymph. It is housed within a bony case (a) and attached to the walls of the latter by connective-tissue fibres (b) in a manner similar to the way in which balloons or dirigibles are anchored (A).

The floor of the balloon contains the recording instruments (d). It consists of a layer of columnar hair cells from whose free end projects a rigid hair process (f). Between these sensory cells are several rows of supporting rod cells. Upon these cells lies a gelatinous layer (e). Beneath the layer the rod cells form tiny vaults, each containing a sensory cell. The entire arrangement resembles a candlestick in an altar niche, and the hair process of the sensory cell projects freely into the space of the niche like a candle flame [Fig. 347]. Just as a candle flame flickers when an air current strikes it, so the hair of the sensory cell vibrates when the quiet of the microscopic space is disturbed. Such a disturbance occurs when the position of the head changes [Fig. 347]. Crystals or concretions of calcium salts are attached to the projecting hairs of the sensory cells. If the head is kept erect, the pressure exerted by the concretions is distributed equally upon the lymph and the hairs within the tiny vaults. On the other hand, if the head is inclined to one side or the other, the con-

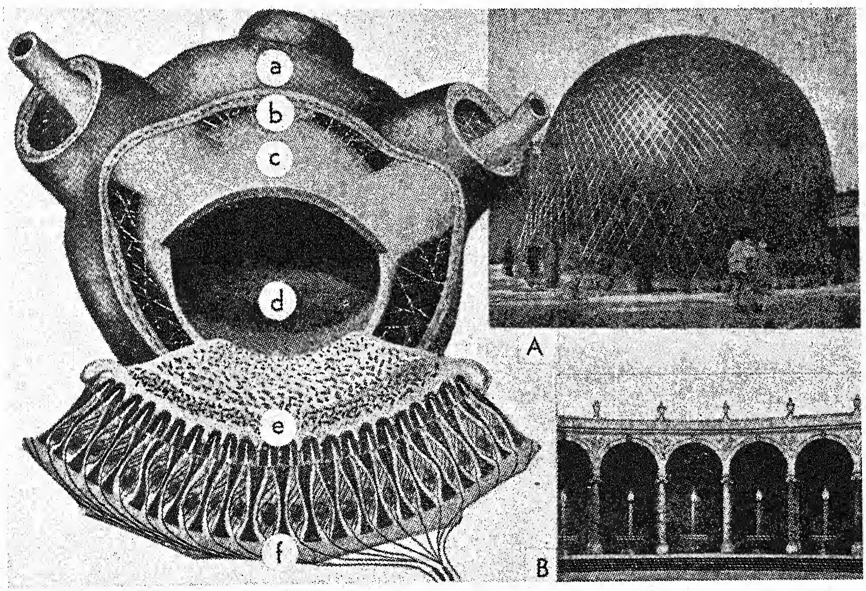


FIG. 346. *The human apparatus of balance (Left) is suspended from delicate filaments, like a balloon inside its net (A). The sensory cells (f) stand erect like candles inside tiny vaults (B), their delicate hairs ready to detect the slightest change of position.*

cretions change their position and move to the inclined side, thus altering the pressure relations and stimulating the sensory cells. The latter in turn send nerve impulses to the cerebellum, where the reflex mechanisms for the maintenance of equilibrium are activated to send strong tonus impulses to the muscles of the opposite side of the body. In this way the body automatically adjusts itself and returns from an inclined to an upright position [Fig. 284 (1-16)].

The Loss of the Equilibratory Apparatus. The two organs of equilibrium constantly send tonus impulses to the cerebellum. If a pigeon is deprived of the right equilibratory organ, the muscle tonus on the right side of the head and neck becomes weaker and the more powerful musculature of the left side draws the head to the left [Fig. 349]. The head of a pigeon deprived of both labyrinths, as this most complicated part of the animal body is called, becomes so weak that a couple of cherries put in the bird's beak suffice to maintain it in a twisted position. And when the atonic head is put into water, the animal no longer has the energy to withdraw it, nor does it feel any need to do so, because, having lost its faculty for spatial orientation, it does not appear to notice that its head is inverted.

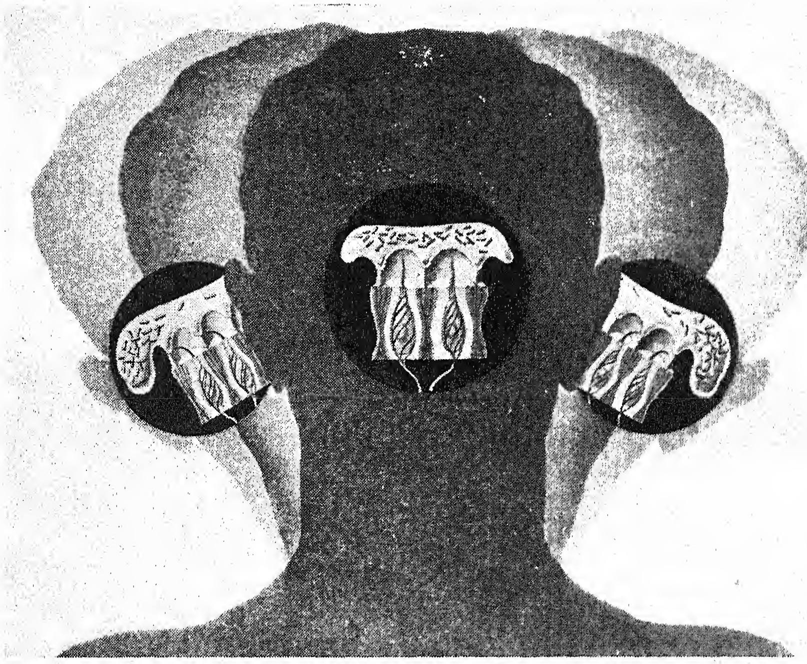


FIG. 347. *The organ of balance, when the head is erect and when it is inclined to either side. Note the bending of the sensory hairs and the displacement of the tiny crystals.*

The Semicircular Canals. The equilibratory organs are "static" apparatuses. Like a pendulum or a hydrostatic level they inform one of

the position of the head in relation to the centre of the earth. As the lower animals developed into vertebrates, thus improving their locomotion, they had to have a "compass," just like a ship or an aeroplane, to indicate the direction in which they were moving. Space has three dimensions: length (backwards and forwards), breadth (right and left), and height (up and down).

Balancing Canals

Corresponding to these dimensions, three elongated tubes grew out of the sac of the equilibratory organ. Since they describe semicircular arcs, they are called semicircular canals [Fig. 353 (10)]. They are placed approximately at right angles to each other in the three dimensions of space [Fig. 348]. At one end of the fluid-filled semicircular tubes there is a bulb-like enlargement, or ampulla. These ampullæ are static organs responding to stimuli of differential pressure. A group of sensory cells, bearing stiff hairs which project into the cavity of the ampulla and are connected with nerve fibres, form a device (see lower right-hand corner of Fig. 350) which is stimulated by the movement of the fluid within the tube whenever the apparatus is tipped into a new position. Since the semicircular canals occupy three different planes, the combined stimuli received by all the three ampullæ make it possible to detect any shift in position, and so to initiate the muscular responses necessary for the maintenance of equilibrium.

For example, we get into a car and start out for a drive (a). What happens? The motor-car travels forward and from under us, so to say, tending to leave us behind because of our inertia. We are pressed against the back of the seat. The lymph in the semicircular canals also remains behind, so that such movements create currents in the fluid due to its inertia. The superior and the lateral canals do not register any reaction because their sensory hairs are not bent by the moving lymph. However, in the inferior semicircular canal, which responds to motion in a forward or backward direction, the sensory hairs are bent backward by the pressure of the moving lymph. Bending of the hairs excites the nerves with which they are connected and we feel that we are travelling forward (b).

After several seconds the lymph as well as the entire body acquires the same velocity as the motor-car, and we no longer notice its motion because the sensory hairs in the canal are again erect (c). We see an obstacle in the road and put on the brakes quite suddenly. Our body retains its velocity and slides forward. The same thing happens with the lymph. As a result it bends the hairs forward, and we perceive the pull on the hairs as a slowing up of our forward motion (d). When we travel around a curve the lymph in the lateral semicircular canals is set in motion.

Travelling in a Lift

If, moreover, we leave the car and travel upward in an elevator, the sensory hairs of the superior semicircular canal are bent downwards when the elevator starts (e), and straighten out while travelling (f). When the elevator stops, they continue to travel in the same direction and are consequently bent upwards (g). In this manner the hairs of the three semicircular canals inform us of the

movements of the body in the three planes of space.

Vertigo. If one revolves rapidly in a circle, the lymph in the horizontal semicircular canal bends the sensory hairs backwards. On stopping, the lymph, which retains its rotary motion owing to inertia, presses the hairs in the opposite direction, so that it seems as if one were now revolving in the opposite direction. However, since our legs and critical judgment tell us that we are stationary, we solve the contradiction by assuming that the world is revolving around us in the reverse direction. In other words, we are dizzy.

Seasickness. Seasickness is an attack of " madness " in the labyrinth apparatus. On a storm-tossed ship the concretions in the equilibratory apparatus are shaken back and forth as the position of the deck changes under one's feet. The lymph in the labyrinth canals rocks back and forth like the water in the carafe attached to the cabin wall; the sensory hairs whip back and forth; the nerve impulses to the cerebellum are switched on and off; each order follows on the heels of the preceding one, every command contradicts that which preceded it, and if an order does reach its destination, the position of the ship has already changed, the order is superseded and countermanded. The result is a state of anarchy in the nervous system in accordance with the famous principle: " *ordre — contre-ordre — désordre.*" The consequences of this condition are headache, dizziness, ringing in

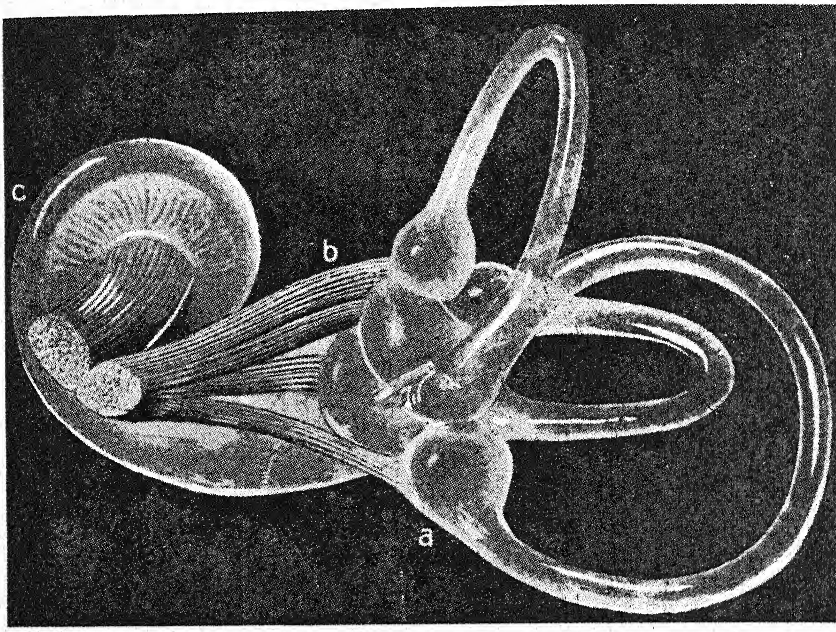


FIG. 348. *An elegant example of Nature's workmanship—(a) the three semicircular canals for detecting the body's movements in space, (b) the equilibratory mechanism for determining the position of the head (centre of picture), and (c) the cochlea.*

the ears, spots in front of the eyes, pallor, flushes, cold sweats, lowering of the blood-pressure, retching, and vomiting—in a word, seasickness, the condition for which no remedy exists, nor can exist unless one finds some means of bringing the lymph in the semicircular canals to a standstill or of eliminating the influence of the nerves that innervate the canals.

Remedies against Sea- and Air-sickness. All existing remedies against seasickness and its modern variant, airsickness, act upon the consequences but not the causes of these conditions. They paralyse either the cerebral cortex, the brain stem, or the vomiting centre in the medulla, or like cocaine they decrease the sensitivity of the mucous membrane they stimulate the sympathetic system, or raise the blood-pressure—but they do not allay the unrest of the lymph in the semicircular canals, which is the cause of seasickness.

At present there is no better remedy than to betake oneself to the steadiest part of the ship—that is, its centre in the neighbourhood of the smoke-stacks—and to remain there as quietly as possible. As in all other morbid conditions, will and imagination play a large part. Fear, as well as thinking and talking about it, favour seasickness. People who are afraid are made seasick by the odour of the ship and the idea of future storms which it rouses, while a courageous person overcomes even severe attacks. The large part played by will in this disease is shown by the fact that in times of danger seasickness vanishes even among those most severely affected. No one has ever been drowned because of inability to leave his cabin in consequence of seasickness. But in order to produce such volitional miracles an ordinary mortal has to feel that death is at his heels, because a diminution of will-power is one of the signs of seasickness.

Deaf-Mutes. Deaf-mutes are people who have not learned to speak because they were born deaf or lost their hearing in early youth. In one-fourth of these deaf-mutes the inner ear, including the semicircular canals and the equilibratory apparatus, is more or less degenerate. It

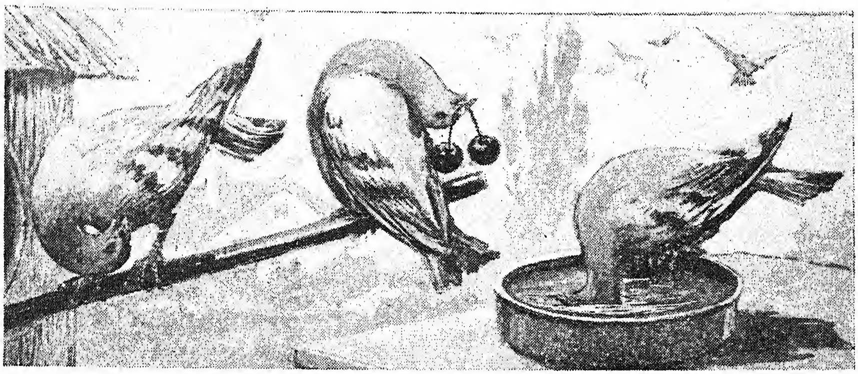


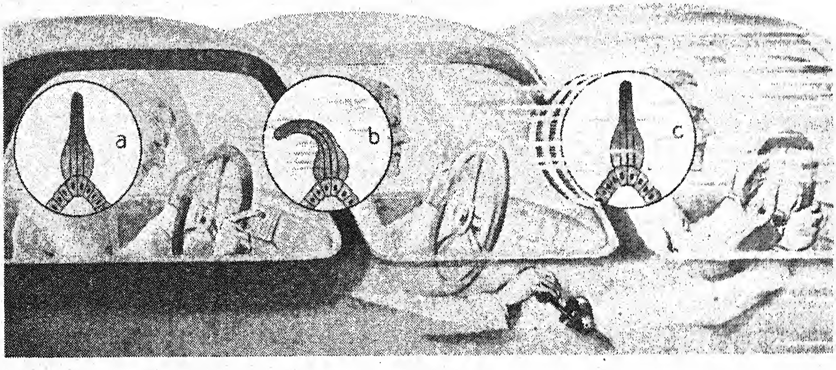
FIG. 349. *If a bird is deprived of its organs of equilibrium, it is unable to control the position of its head, and does not seem to realize that it is inverted.* (*Page 508.*)

lacks sensory hair cells. Because all children possess extraordinary dexterity, deaf-mutes learn to walk with the help of visual control and the muscle sense. But they remain awkward and uncertain in the dark. They are poor swimmers and cannot dive. Since they have no sensory hairs, they do not become dizzy or seasick. But this is the only advantage which they obtain from their infirmity.

How Hearing Developed

The Auditory Apparatus. The auditory apparatus is a grandchild of the organ of equilibrium. Aquatic animals developed an organ of equilibrium, and when they acquired greater freedom of motion they added the semicircular canals to control the direction of their movements. When aquatic animals left the water in the course of evolution, the gill clefts became superfluous and were rebuilt to serve other functions [Fig. 26]. The first gill cleft, which had previously been a canal for water, now became a canal for atmospheric air. At the same time the organ of equilibrium gave rise to a new instrument of orientation, a fourth semicircular canal, which gradually grew longer and eventually curled up like a snail [Fig. 348 and Fig. 353 (12)]. No doubt for millions of years the amphibian animal forms that were transitional between true aquatic and land animals and whose bodies were not yet elevated by means of supporting limbs from contact with solid earth had no true organs of hearing. The vibrations which were of the greatest service to them and for which their sense organs were especially adapted were probably seismic rather than auditory in character. With the elevation of the head from the ground and the simultaneous refinement of these sensory organs they began to perceive vibrations that passed through the air—sound waves—with the result that in the course of millions of years the organ of equilibrium developed into a true sense organ of hearing.

The human auditory apparatus is composed of three parts: the outer ear, which collects vibrations from the air; the middle ear, which amplifies them and transforms the



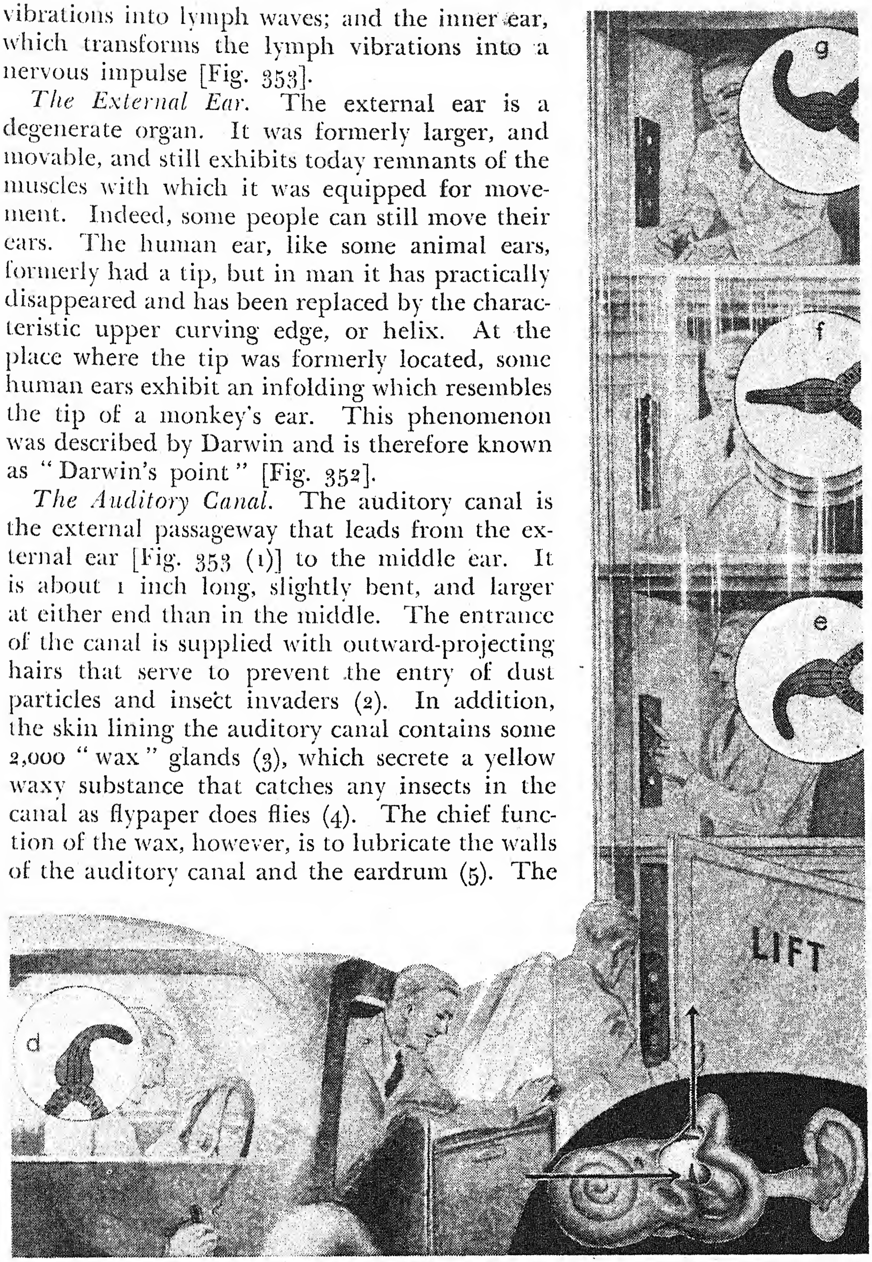
(a) at rest. (b) starting. (c) driving.

FIG. 350. *How motion is detected by the equilibratory mechanism of the ear. The pictures (a—d) illustrate successive stages of horizontal motion. The sensory hairs*

vibrations into lymph waves; and the inner ear, which transforms the lymph vibrations into a nervous impulse [Fig. 353].

The External Ear. The external ear is a degenerate organ. It was formerly larger, and movable, and still exhibits today remnants of the muscles with which it was equipped for movement. Indeed, some people can still move their ears. The human ear, like some animal ears, formerly had a tip, but in man it has practically disappeared and has been replaced by the characteristic upper curving edge, or helix. At the place where the tip was formerly located, some human ears exhibit an infolding which resembles the tip of a monkey's ear. This phenomenon was described by Darwin and is therefore known as "Darwin's point" [Fig. 352].

The Auditory Canal. The auditory canal is the external passageway that leads from the external ear [Fig. 353 (1)] to the middle ear. It is about 1 inch long, slightly bent, and larger at either end than in the middle. The entrance of the canal is supplied with outward-projecting hairs that serve to prevent the entry of dust particles and insect invaders (2). In addition, the skin lining the auditory canal contains some 2,000 "wax" glands (3), which secrete a yellow waxy substance that catches any insects in the canal as flypaper does flies (4). The chief function of the wax, however, is to lubricate the walls of the auditory canal and the eardrum (5). The



(d) stopping. (e) starting. (f) travelling. (g) stopping.

of the inferior canal are bent forwards and backwards and inform the brain accordingly. At (e—g) are seen the reactions of the superior hairs to vertical motion in a lift.

M.S.F.—R*

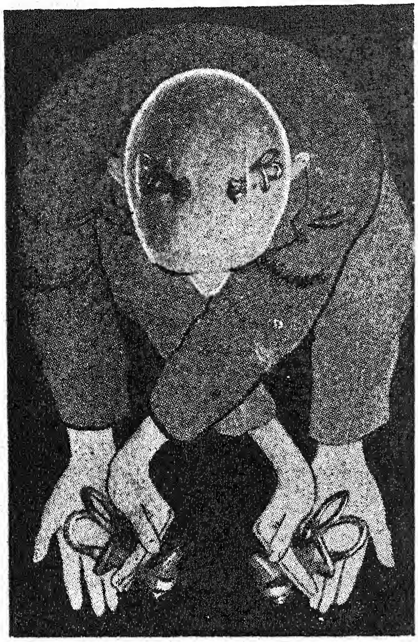


FIG. 351. *Placing the hands in the position shown above is an aid to visualizing the arrangement of the semicircular canals, with their three spatial planes arranged at right angles to one another.*

auditory canal is the " mouthpiece " of this musical apparatus. Like the trachea in the vocal apparatus, its cavity encloses a long column of air of an even, moderate temperature. This column of air forms the constant fundamental mass for the sound configurations that pass through the auditory canal and impinge upon the eardrum. At the same time it isolates the " musical instruments " of the middle ear against all the disturbing influences arising from temperature changes in the outer world.

The Middle Ear. The middle ear is a space about as large as a pea. It is an irregular air-filled chamber, hollowed out of the temporal bone. Stretched across the inner end of the auditory canal and separating it from the middle ear is the tympanic membrane, or the eardrum as it is commonly known (6). The sound vibrations that impinge on the eardrum are carried across the middle ear and intensified in their passage to the inner ear by the auditory ossicles (7).

Ear Infection

Inflammation of the middle ear is generally a catarrhal condition that results from cold, influenza or measles. The infection generally ascends from the pharynx to the middle ear by means of a passageway, the Eustachian tube (8), and often leads to suppuration involving both the tympanic cavity and the cellular mastoid process located behind it. This necessitates incision of the eardrum, or, if this does not suffice, opening of the mastoid cavity.

The Eardrum. As mentioned above, the entrance to the middle ear is closed by a membrane, the tympanic membrane (6), set obliquely across the passageway of the auditory canal. An advantage of the oblique position is that a greater expanse of surface is exposed to the vibratory stimuli than would be possible if the membrane extended squarely across. The structure of the membrane is analogous to that of a parasol. Delicate fibres run concentrically, while strong fibres, corresponding to the ribs of an umbrella, pass from the centre to the periphery. The delicate fibres are elastic so that the membrane can expand and contract under the impact of the air. The coarse fibres are springy, like the ribs of an umbrella, and do not change their length. Owing to this structure the drum is very strong.

It withstands the pressure of a column of mercury one metre high. In addition it also has a special "valve" as a protection against rupturing; the upper segment is not so tensely stretched as the other parts, but is flaccid. In some individuals the eardrum is congenitally perforated. In some cases it must be opened surgically in order to relieve middle-ear inflammation. The auditory faculty is but little affected by this procedure.

The Eustachian Tube. The Eustachian tube (8) is the ventilator of the tympanic cavity. It is broader at the pharyngeal than at the tympanic end, and remains closed except during the act of swallowing, when it may open far enough to permit an exchange of air within the tympanic cavity. In this way the pressure of the air within the tympanic cavity is so adjusted that it is the same as on the outside of the eardrum.

Firing a Gun

Rupture of the Eardrum. Unusually strong sound vibrations, such as arise when heavy artillery is fired or when lightning strikes, may exert such great pressure on the eardrum that it may rupture [Fig. 354 (A)]. Such a rupture can be prevented by opening the mouth wide when the command to fire is given. If this is done the air presses against the tympanic membrane not only from the outside through the auditory canal, but also by way of the oral cavity through the Eustachian tube, so that the pressure on both sides of the drum is equalized (B).

The Eustachian Tube in Health and Disease. Stop reading for a moment and swallow. In swallowing, the uvula—which may be seen in the centre of Figure 336, suspended from the soft palate—is elevated, the Eustachian tube is opened, and air is pressed into it out of the oral cavity [Fig. 355 (a)]. As mentioned above, this exchange of air serves to adjust the air-pressure within the tympanic cavity so that it is equal on both sides of the eardrum. The wall of the tympanic cavity contains numerous small blood vessels that warm the air within it. Through the very thin walls of these microscopic vessels the blood within them removes air from the tympanic cavity. Respiration is carried on not only

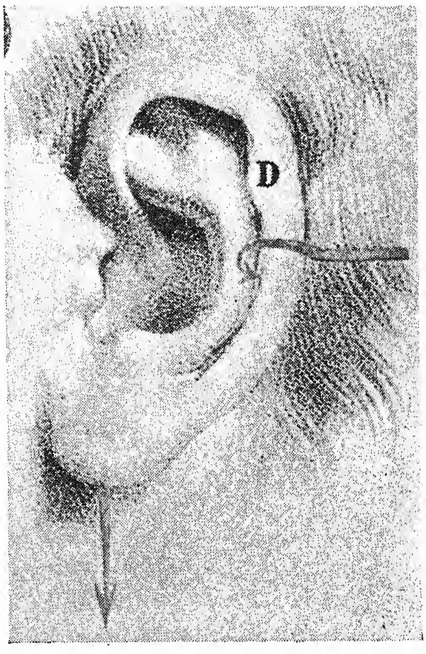


FIG. 352. *The external ear of man is in the process of transformation. Its outer border has turned inward, as is indicated by the horizontal arrow, while its lower edge has become elongated to form the lobe (vertical arrow). Above the horizontal arrow is the so-called "Darwin's point" (D), an infolding believed to represent the tip of the ear in other mammals.*

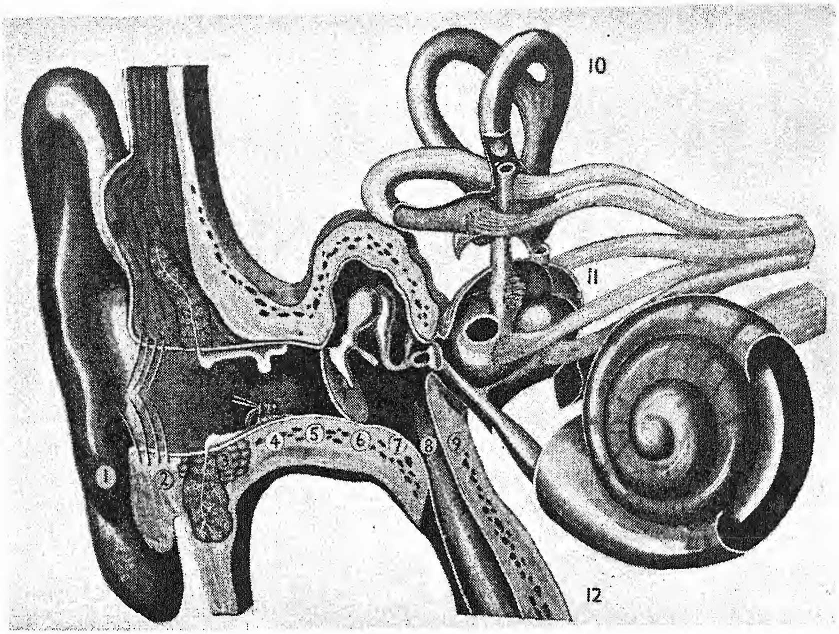


FIG. 353. *The marvellous mechanism of the human ear. (1) The auricle, or outer ear, which gathers sound waves like a trumpet; (2) the protective hairs of the auditory canal; (3) wax glands for lubrication; (4) sticky insect trap; (5) auditory canal; (6) eardrum; (7) the three auditory ossicles; (8) Eustachian tube, which equalizes air-pressure inside the inner ear; (9) bony casing; (10) semicircular canals—a three-dimensional compass; (11) equilibrium apparatus; (12) the cochlea, or organ of hearing*

by means of the lungs but also through the tympanic cavity. To be sure, the quantity of air removed is very small, only about one tablespoonful of air between two swallows. If a vacuum arises in the tympanic cavity, hearing becomes difficult or even impossible. When one has a cold, the pharyngeal opening of the Eustachian tube becomes swollen, making it impossible for air to enter the tympanic cavity. In consequence a vacuum is created in the tympanic cavity and one has difficulty in hearing. The pressure of the atmosphere against the eardrum meets with no resistance within the tympanic cavity, the drum is pushed inward, and one feels that the ear is clogged (c). When the patient visits a doctor, the latter remedies the condition by inserting a thin tube into the mouth of the Eustachian tube and blowing some air through it by means of a rubber balloon. A healthy person, whose pharynx and Eustachian tube are not affected in any way, can carry out this treatment himself. The mouth and nose are kept closed, while at the same time an attempt is made to exhale. The air from the lungs cannot escape and ascends through the Eustachian tube into the tympanic cavity, as in the left half of (b). If the eardrum is perforated, the air escapes through the ears. One can do the same with a mouthful of smoke, in which case

the smoke will be seen emerging from the ear, as shown in the right half of (b).

The Auditory Ossicles. The sound waves that impinge on the eardrum are transmitted to the inner ear and amplified in the course of this passage by a system of three tiny ear bones, or auditory ossicles: the hammer (*malleus*), the anvil (*incus*), and the stirrup (*stapes*) [Figs. 344, 353, 356]. The ear bones are the smallest bones of the skeleton, and are not much larger than the letters on this page. They are articulated with each other by means of joints. Two tiny muscles, the smallest in the body, attached to the hammer and the stirrup, regulate the tension of the tympanic membrane and the contact between the bones. The entire system consisting of the three auditory ossicles is a "driving-gear" mechanism, analogous to that of a motor-car. Although they are essentially quite different, yet both the motor-car and the ear exhibit certain remarkable parallels [Fig. 356]. In the first place, both are compression motors. A motor-car makes use of the motive power furnished by a compressed and then ignited gas; in the ear the motive impulse is provided by the compressed air of the sound waves. In the motor-car the mechanism is activated by the pressure created by the ignition, in the ear by the pressure of the sound waves. The second parallel is the fact that in the ear as well as in the motor-car the compression pressure is first transmitted to a large freely vibrating middle piece, the flywheel in a motor-car, the eardrum in the ear. The third point of resemblance is the "translation," by means of a gear mechanism in both cases, of movements of great amplitude into movements of diminished amplitude but increased power. In the motor-car this translation is performed by the driving gear, a system of interlocking gear wheels; in the ear by the system of the three auditory ossicles. This translation is necessary (fourth point of similarity) because in both mechanisms the movement of gases must

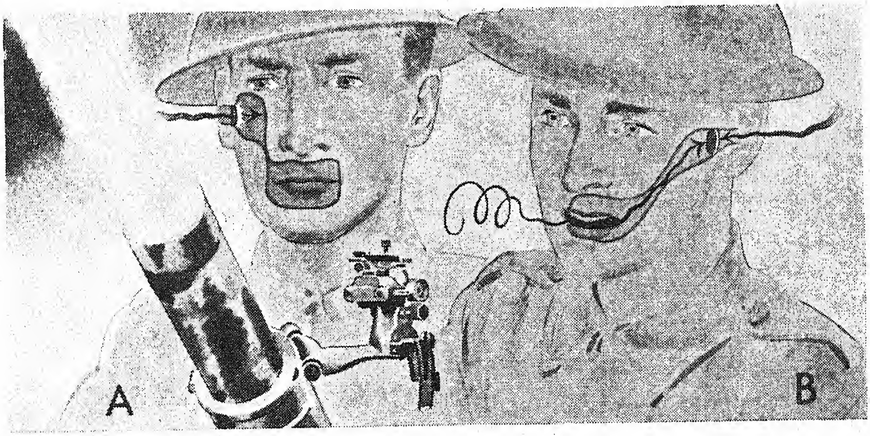


FIG. 354. *Excessive air-pressure, such as accompanies the firing of a gun, may cause tearing of the eardrum. But if the mouth is kept open during firing, the air-pressure is equal on both sides of the eardrum, and no damage results.*

be transformed into a movement of massive parts. In a motor-car small pistons are moved back and forth by the pressure of the gas, and this motion of relatively little energy is transformed by the gear system into the revolution of heavy wheels. In the ear the vibrations of the air in the cylinder of the auditory canal must be translated into the vibrations of the lymph in the spirally wound cochlea. The three auditory ossicles are a "gear mechanism" which translates the large vibrations of the eardrum into the 23 times smaller vibrations of the column of water in the snail-shaped canal of the cochlea [Fig. 356 (a, b)].

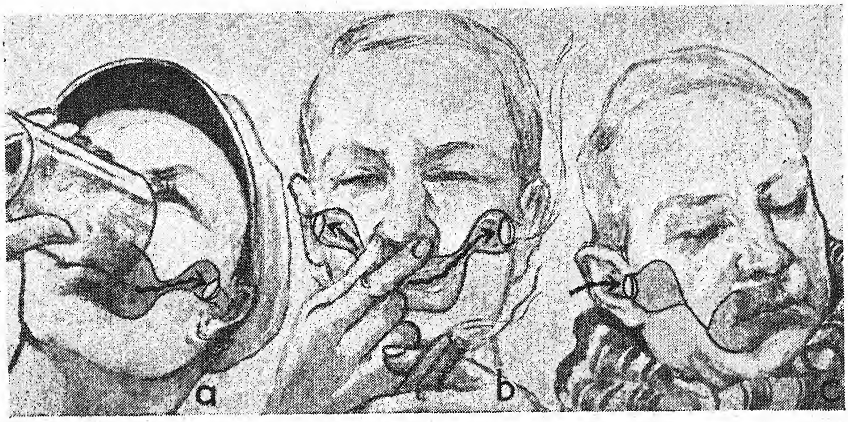


FIG. 355. *The air-pressure within the Eustachian tube is subject to variation. Normally, whenever we swallow (a), some air is pushed through the Eustachian tube into the middle-ear cavity. If the mouth and nose are closed (b) and the air within them is compressed, it passes into the middle-ear cavity and produces excessive air-pressure behind the eardrum. Negative pressure (c) may result from a head cold. The Eustachian tube is swollen and obstructed, the air in the middle-ear is absorbed, and external air pressure pushes the drum inwards, causing a feeling of discomfort.*

The Cochlea. The cochlea, the part of the auditory apparatus which contains the specific organ of hearing, is a musical instrument of complicated structure, resembling that of a piano. In order to comprehend its construction, let us imagine that we are observing an instrument-maker at work [Fig. 357]. He takes a piece of bone, clamps it in a vice, and bores a spiral passage in it which runs two and a half times around a central axis. Reversing the borer, he makes a similar descending tube. Between the ascending and the descending passages he leaves a wall (a). From this wall the instrument-maker then breaks off the outer part, removing more of the wall in the upper part of the spiral tube. The space thus created is 0.16 inch wide at the bottom of the tube and expands increasingly as it passes upward until it is 0.2 inch at the top (b). Then he drills a few delicate canals through the axis, or spindle as it is called, of the snail-like structure and extends them to the edge of the remaining section of the wall (c). The resemblance to a violin bridge is striking, and it becomes even greater as we follow the

construction in its further stages.

Upon the remaining section of the wall, which projects from the axis like a balcony, he mounts a plate consisting of firmly felted connective-tissue fibres. On this plate he moulds several rows of teeth similar to the steel hitch-pins that pianos have for the attachment of the strings [Fig. 358 (a)]. From these teeth he stretches strings to the opposite wall, and like a piano-maker he combines them in groups of three to six to form chords (b). Since the space at the bottom of the spiral tube is narrow, he uses short, delicate strings here. The higher he ascends in the spiral, the longer and thicker do the strings become, until he finishes at the top with bass strings. A piano-maker uses about 240 strings; the constructor of the cochlea requires exactly one hundred times as many—24,000! Since the cochlea in a pianist's ear is approximately a million times smaller than the piano upon which he plays, one must imagine the keyboard and strings of a concert piano reduced about 100 million times in order to arrive at the dimensions of the auditory "piano" in the ear.

The Keyboard. Now the instrument-maker, using a forceps, picks

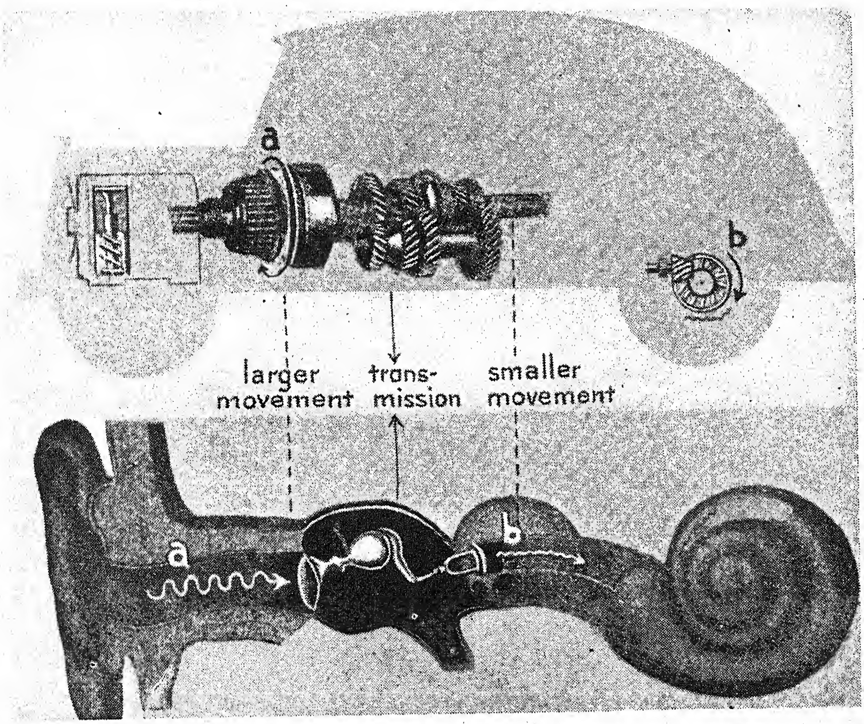


FIG. 356. *The auditory ossicles of the ear operate like the transmission mechanism of a motor-car. The function of these three tiny bones—smallest in the body—is to transform one type of motion into another, just like the motor's transmission system. In the case of the ear, the relatively large, free vibrations of the drum (comparable with a flywheel) are transformed into minute movements in the cochlear fluid.*

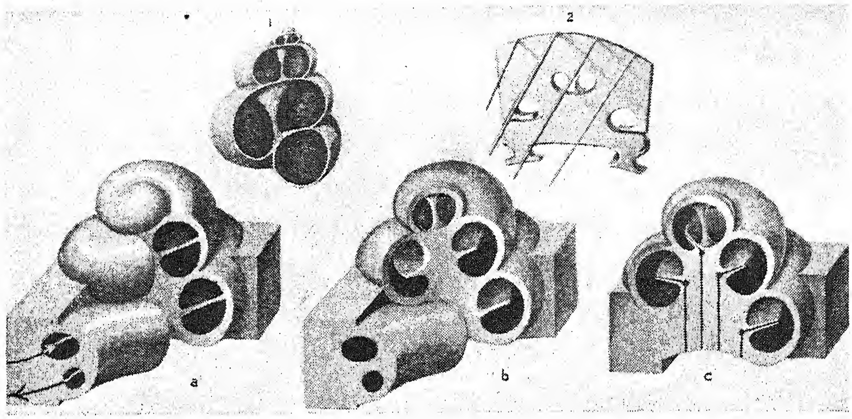


FIG. 357. *Building an auditory piano—the construction of the cochlea. Taking a snail shell (1) as model, a double passageway is drilled spirally through a bone (a). Part of the dividing wall is removed (b), leaving a platform. Then fine canals are bored through this structure (c), which in section now somewhat resembles a violin bridge (2).*

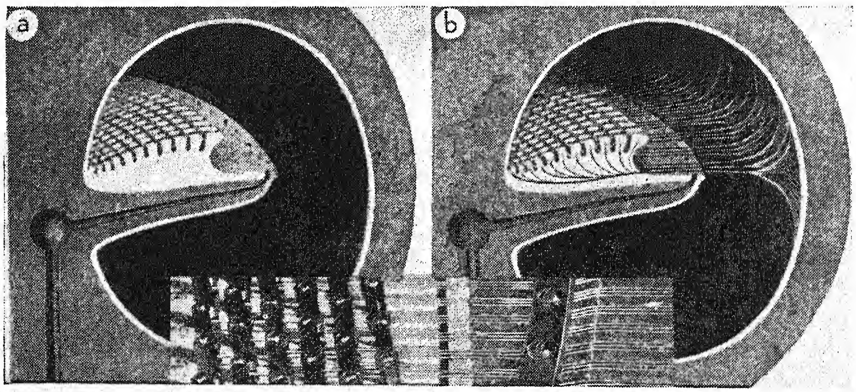


FIG. 358. *Next, hitch-pins are mounted upon the projecting platform (a), and strings are stretched from them to the opposite wall (b) in groups, like the strings of a piano.*

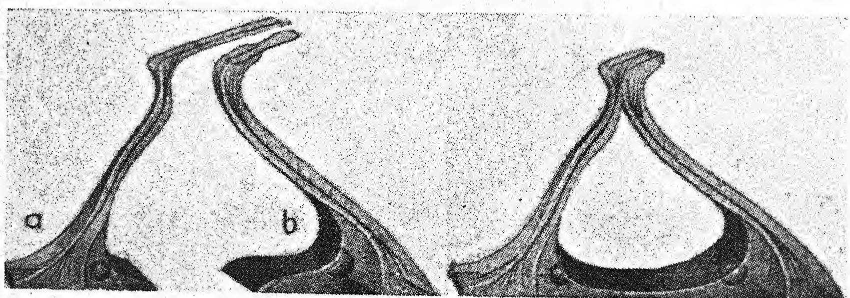


FIG. 359. *Two types of supporting pillar cells (a, b) are fitted together to form an arch. The lower part of each cell is alive; the remainder is formed of springy horn rods.*

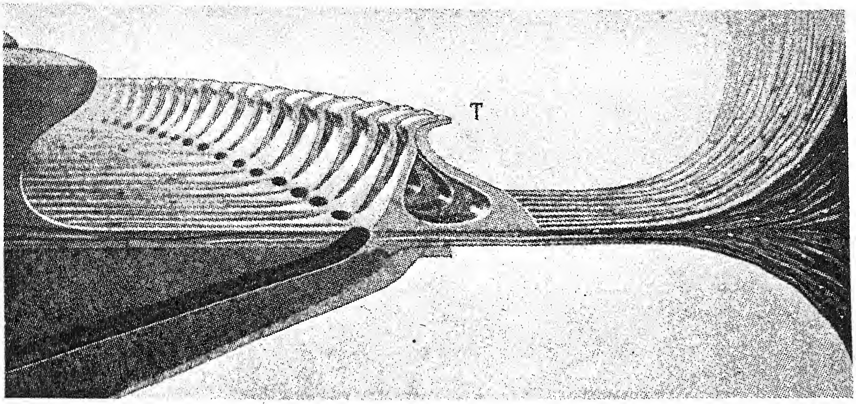


FIG. 360. *Above each group of strings shown in Fig. 358 (b) is mounted an arch like that in Fig. 359. Ranged thus together, side by side, these arches form a long tunnel (T).*

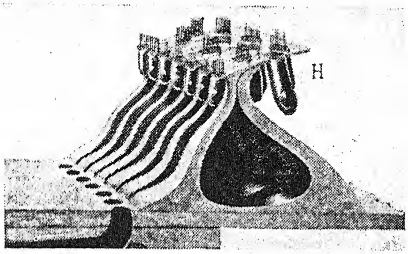


FIG. 361. *A further stage in the building of the auditory piano. Auditory cells (H), resembling cucumbers cut in half, are attached to the arches of supporting pillar cells. Each auditory cell is furnished with slender bristles, which act as sensory hairs.*

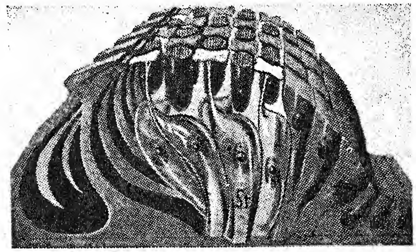


FIG. 362. *In order that several rows of auditory cells can be installed, additional supporting cells, shaped like bottles (St), are fitted. To the narrow necks of the "bottles" are attached supporting plates, from which more auditory cells are hung.*

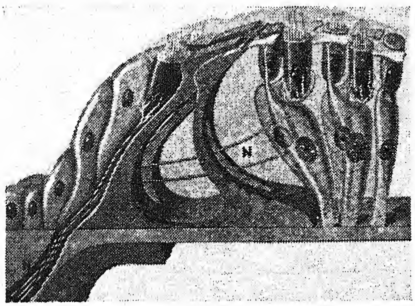


FIG. 363. *From each of the auditory cells connections are made to the nervous system by means of nerve cables (N), introduced through the tiny canals and openings.*

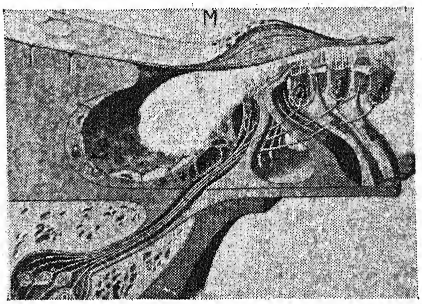


FIG. 364. *Above the auditory cells and their tiny projecting sensory hairs is now fastened a thin membrane (M), which under light pressure impinges upon the hairs.*

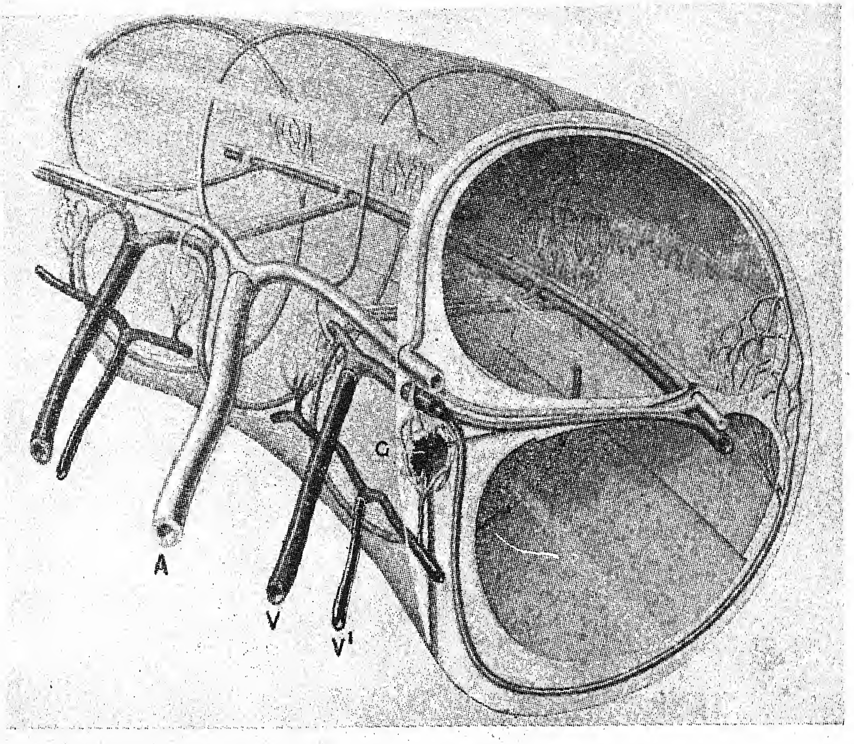


FIG. 365. *In order to nourish the cells of the "auditory piano," blood vessels are introduced through its bony walls. (A) represents an artery, with its branches; (V) and (V1) are veins, while (G) is a network of blood vessels surrounding a nerve ganglion.*

a number of cells out of a box and constructs the keyboard with them. First he takes two types of supporting pillar cells which fit together like a box and its cover [Fig. 359]. Each supporting cell consists of two parts. One of these (dark in the drawing) is alive; it contains a granular protoplasm together with the cell nucleus, and nourishes the cell. The other upright portion is a supporting pillar and contains bundles of springy horn rods. Some of the supporting cells are inclined to the right and others to the left. The instrument maker takes one of each and places them so that they lean against each other, forming an arch. He then puts the arches above the point of attachment of the strings [Fig. 360]. By placing an arch over each group of strings the pillars form a tunnel (T).

"Cucumber" Cells

On the plates of the supporting cells he hangs small dark auditory cells resembling cucumbers that have been cut in half [Fig. 361 (H)]. In the cut surfaces he places fine bristles that are to serve as sensory hairs. In the smaller auditory cells he mounts the hairs in a single row, while in the larger ones many more are inserted--indeed as many as one hundred hairs in some cells. In order

to provide the support for the auditory cells so that several rows of them can be installed, he makes special supporting cells shaped like bottles [Fig. 362 (St)]. He solders supporting plates to the narrow necks of the bottle cells, and suspends more auditory cells in the spaces between the plates. In these spaces the auditory cells swing as freely as bells [Fig. 362].

Nerves of Hearing

The Innervation of the Cochlea. After the auditory cells have been suspended in their places, the instrument-maker introduces nerve cables [Fig. 363 (N)] through the canals and openings of the spindle. At the base of the auditory cells these cables are unravelled so that each auditory cell is surrounded by a network of nerve endings. An instrument-maker who constructs an auditory piano such as we are describing must be industrious and have a great deal of patience; he must attach more than 20,000 strings and mount approximately 100,000 auditory cells.

The Tectorial Membrane. After all the auditory cells have been hung in their places and all the sensory hairs have been inserted, a thin projecting flap is now fastened above the keyboard. This flap, which is known as the tectorial membrane, probably impinges lightly upon the upright sensory hairs whenever it is agitated [Fig. 364]. Then he stretches a broad membrane transversely across the interior of the entire spiral tube, thus dividing it into three segments of approximately equal size. The upper and lower spaces are free from the vibrations of the sound waves, while the

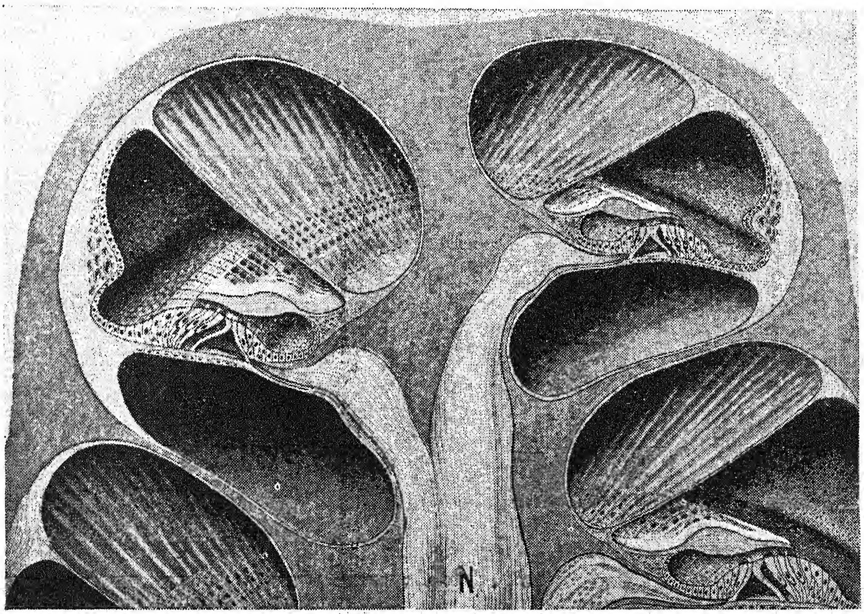


FIG. 366. *Across the spiral passageway, throughout its entire length, a delicate membrane is stretched at an angle. The passageway has already been partitioned (Fig 357), and now consists of three spaces. The middle space contains the "keyboard."*

centre one contains the keyboard [Fig. 366].

The Lymph. The spaces do not remain empty, but are filled with lymph. The instrument - maker brings tubes through the bony wall [Fig. 365], light arteries (A) and dark veins (V), and from the main tubes branches are extended underneath the keyboard. In addition, other branches are laid circularly around the spiral tube, while each individual nerve node in the wall is surrounded by a special network of delicate vessels (G). Finally, he lays another tube beneath the arched tunnel formed by the pillar cells. Attached to this coarse network of blood vessels is the much finer and much more ramified system of lymph-vessels from which the lymph in the cochlea is obtained.

Resonance

The Window Membranes. To prevent the lymph from flowing out of the cochlea, so that the completed organ will be filled with the fluid, the instrument-maker closes the two drill holes at the base of the spiral tube with membranes. These two holes are known as the two windows, the oval and the round. The third auditory ossicle, the stapes, is attached to the outer surface of the membrane covering the oval window, thus transferring to the lymph of the inner ear the sound vibrations that strike the drum [Fig. 356 and Fig 344 (d)].

The Cochlea — a Resonating Piano. If the cochlea which has been constructed before our eyes is regarded as a musical instrument, it is seen to bear the greatest similarity to a grand piano. Our auditory apparatus is an auditory piano. Since it is not played directly, but resonates like a radio apparatus when it receives appropriate waves from the external world, it is a resonating piano.

A person sits down at a piano and strikes the concert pitch A. The A string vibrates 435 times per second and consequently sends 435 wave impulses that impinge on the eardrum.

A Human Piano

These waves are passed by the auditory ossicles to the oval window and by the latter to the lymph in the cochlea, where they set into vibration that group of strings among the 24,000 of the auditory piano which because of their length and tension oscillate with the same vibration rate [Fig. 367]. If the player strikes a chord consisting of three tones, three groups of strings vibrate in the auditory piano; and if he plays a Beethoven sonata, the strings in the auditory piano of his ear vibrate in the same order as those in the concert piano. A person sitting at a piano plays not one, but two instruments, the large wave-producing piano before him, and the small wave-receiving piano within himself. It may well be said that a piano is an apparatus constructed by man in order to set the strings of the auditory piano in the ear vibrating according to continual variations of tone.

Extremes of Tone

Capabilities and Defects of the Auditory Piano. A grand piano has a range of 7 to 7½ octaves. The keyboard of the cochlea extends one octave deeper and four octaves higher. The longest and thickest strings at the top of the cochlea vibrate at the rate of sixteen oscillations per second, while the vibration

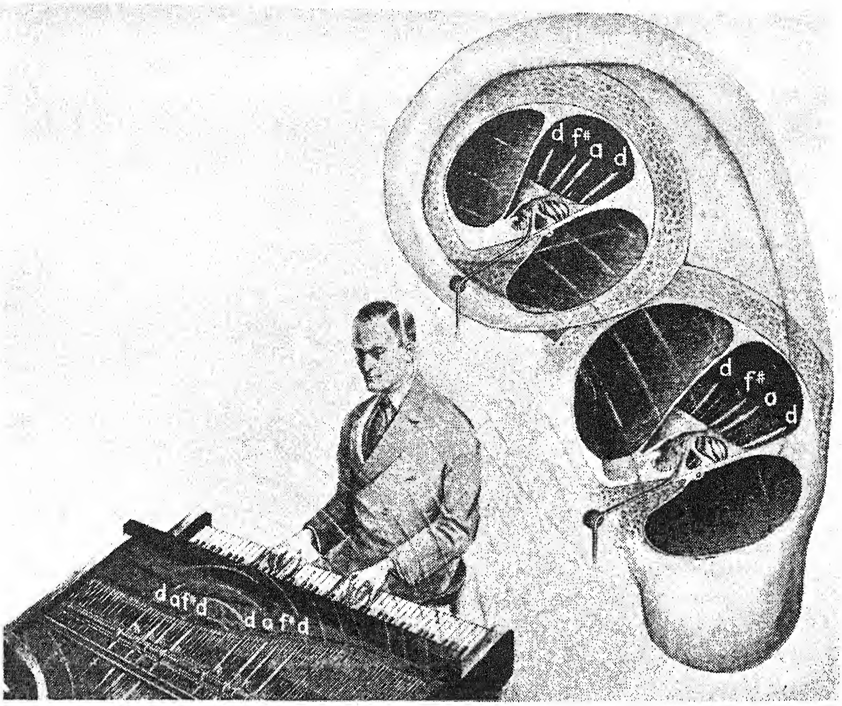
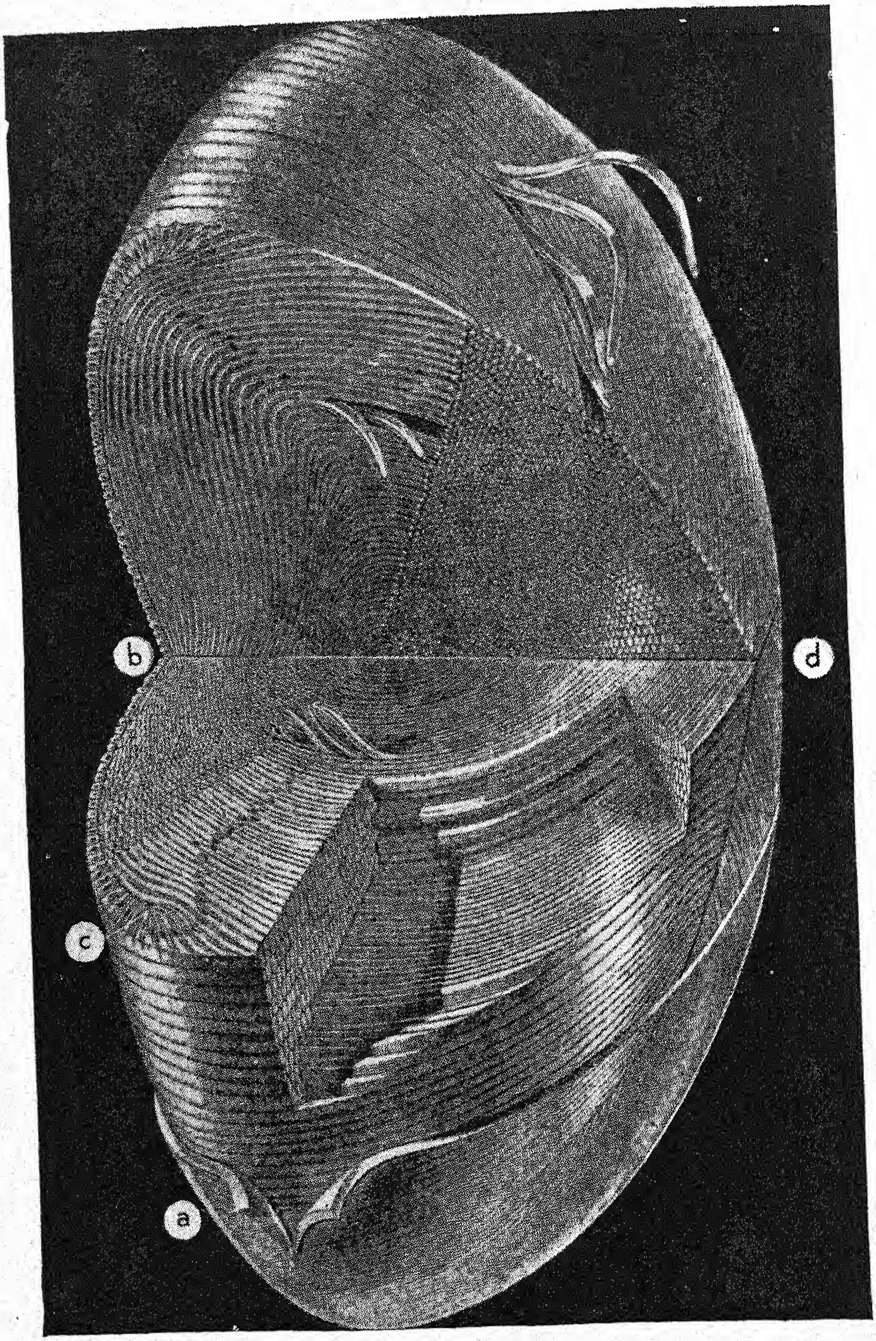


FIG. 367. *The auditory piano is finished at last! Now it only remains for us to try it out. We sit down at the keyboard of a real piano, strike the common chord of D major—D, F sharp, A, D—and observe the auditory piano. Within it, in accordance with the law of resonance, vibrate strings of the same pitch as those in the real piano.*

rate of the shortest and most delicate strings at the base of the cochlea is twenty thousand per second. Animals in which different parts of the cochlea have been destroyed give evidence of deafness to high notes when the short strings are damaged, deafness to low notes when the long strings are removed. If individual groups of strings are destroyed, islands of deafness appear, just as tone gaps appear in a piano from which certain strings have been removed. If the natural vibratory period of the strings is changed, owing either to stretching or to inflammation, as occurs in certain diseases, then the auditory piano is out of tune. Should this occur unilaterally, so that one ear hears tones normally while the other perceives them a half tone lower, it produces dissonances that are just as unpleasant as if in a violin duet the instruments were differently tuned.

The auditory faculty is most highly developed in early youth and declines from decade to decade. A child hears 20,000 vibrations per second; at the age of thirty, one can hear only 15,000 vibrations, while a person of fifty cannot detect sounds that have a natural period of more than 13,000 vibrations a second.



OBJECT-GLASS OF THE EYE

FIG. 368. *The lens of an eye—woven from many layers of cellular fibres.*

CHAPTER XLI

The Eye

THE EYE—A CAMERA. THE CORNEA. TEARS. ASTIGMATISM. THE LENS. ACCOMMODATION. CATARACT. THE IRIS. THE PUPIL. EYE COLOUR. THE RETINA. VISUAL ACUITY. THE VISUAL PURPLE. ADAPTATION TO DARK. THE OPTIC DISK. THE BLIND SPOT. SINGLE AND DOUBLE VISION. THE MUSCLES THAT MOVE THE EYES. THE NERVOUS APPARATUS FOR EYE MOVEMENTS

A PERSON playing a piano is actually playing two pianos. The one is the instrument standing before him, the other that which he has in his ear, the strings of which vibrate in sympathy with the strings in the piano. A person who looks at the world through a camera is looking through two apparatuses: the one which he holds in his hands, and the other situated in his head in the form of the eye [Fig. 369].

The camera (I) apprehends a picture of the external world by means of a lens (b) and projects it on the posterior wall of a box with black walls (c). Here it impinges on a sensitized plate (d), which reacts to light, thus fixing the image. In order to obtain a clearly focused and well-illuminated picture at all times without having to consider the changing conditions of the external environment, the lens is equipped with a diaphragm which contracts the lens aperture as required (a).

The Human Camera

The image apprehended by the camera enters the eye (II), which, remarkably enough, is constructed like the camera. Anteriorly it possesses a diaphragm which regulates the lens aperture (a), and behind the diaphragm is the lens (b). At the back of the lens is a space (c) the wall of which is formed by a sensitized layer, the retina (d). One can take photographs with the eye just as with a camera. Figure 371 shows the image of a house as it appears on the retina of an eye, where it was photographed.

Giant Eyes

The Eyeball. The eyeball is the term used to describe the eye in its totality, as one sees it for instance when it is removed from the head of a slaughtered animal. The smaller an animal, the larger are its eyes in relation to its total weight. In a newborn child the weight of an eye is $\frac{1}{1000}$ of the total body weight, while in an adult it is only $\frac{1}{10000}$. The size of the eyes also depends on the needs of the particular animal species. The weight of a moor-hen's eye is $\frac{1}{500}$ of the body weight, while that of the kestrel, which must espy its prey from great heights, is $\frac{1}{35}$ of the total weight. Among cuttlefishes one finds eyes having a diameter of $14\frac{1}{2}$ inches. These eyes are twice as large as this page, and in some species the eyes account for one quarter of the

total weight of the animal's body.

The Ocular Fluid. The eyeball is kept tense by its ocular-fluid content; by means of an ingenious system of valves the fluid is maintained under positive pressure. If the eye is pierced, the fluid flows out and the eye collapses like a burst balloon. This does not mean, however, that the eye is lost. If the opening closes, the fluid collects once more, and the balloon fills up again.

"Safety Glass"

The Cornea. On examining the clear anterior surface of the eye, the cornea, one is inclined to assume that it lacks any structure. Actually, however, it consists of several dozen layers of epithelial cells. In its structure it resembles the safety glass used in motor-cars, which is made by cementing together several layers of sheet glass. The cornea can be seen in cross-section in the foreground of Figure 372, and one recognizes that it consists of no less than five layers. The chief portion of the cornea is the middle layer, composed of a thick mass of fibrous connective tissue. The connective tissue consists of bundles of fibres arranged in layers, the direction of the fibres crossing one another at right angles in alternate layers. The anterior and posterior walls of the central layer are each covered by a homogeneous glassy membrane. Both the external and the internal surfaces of the cornea are covered by epithelial cells.

Undisturbed Vision

The fact that the cornea contains so many elements and that we can see through it without being disturbed by them appears very astonishing at first. We know, however, that small spots on our eyeglasses do not disturb us because they are so close. Look at the dot over this *i*. If it is brought close to the eye, it vanishes at a certain distance. In the same way the fibres and cells of the cornea apparently vanish, because owing to their proximity they do not project any disturbing image on the retina.

The Lids—the Windscreen-Wipers of the Eyes. The windscreen-wiper of a motor-car is certainly a practical invention, but it is not new. Several hundred million years ago nature constructed a windscreen-wiper for the windscreen of the eye [Figs. 373 and 374]. It is by no means true that the models of nature in every case surpass the creations of our technology, as habitual glorifiers of nature are wont to announce to the world.

An Imperfect Instrument

The human eye, in particular, when considered as an optical instrument, exhibits such a large number of imperfections that Helmholtz, the greatest authority of the nineteenth century on the eye, said that if an optical instrument-maker were to offer him the eye as an optical apparatus, he would reject it and protest vehemently against the carelessness of its construction. As regards the windscreen-wiper, however, that of the eye is undoubtedly the best model used at present and it would be more of a pleasure to drive a motor-car in bad weather if the car were equipped with a device which performed its function as efficiently as do the lids.

The lids are folds of skin strengthened by plates of fibrous tissue and can be raised and lowered like stage curtains by means of muscles. The

curtain moves so rapidly that it in no way disturbs the enjoyment of the play. Like the windscreen-wiper of a car, they move automatically at six-second intervals, so that during life they are pulled back and forth approximately two hundred and fifty million times.

The Eyelashes and the Eyebrows. At its free edge each lid has a row tats. Above the lashes are the eyebrows, which represent the eaves of the human body. They carry off laterally any rain or perspiration which runs down from the forehead so that the drops will not run into the eyes.

The eyelids also perform the function of automatic lubricators and irrigators. Lubrication of the cornea

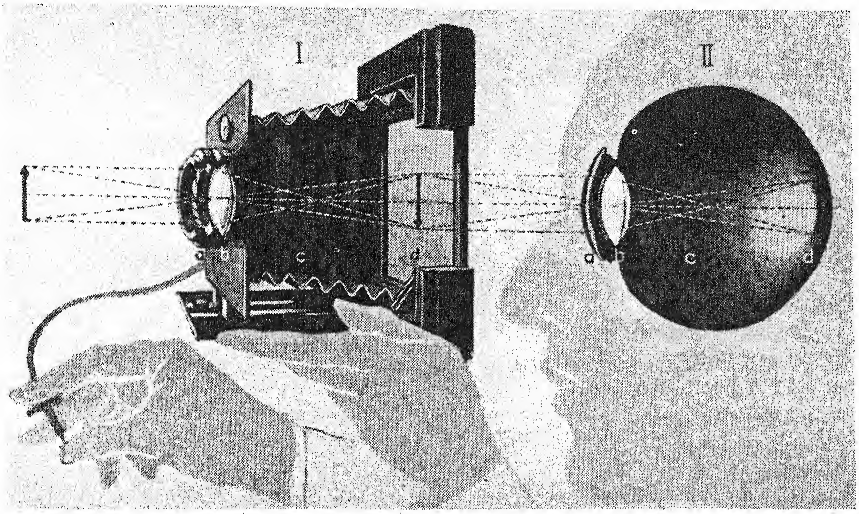


FIG. 369. *A camera and a human eye are remarkably alike in their construction, and the principles upon which they operate are also similar. In both devices an image of the external world is brought to a focus by means of a lens (b), and projected upon a screen (d) which is sensitive to the influence of light.*

of short curved hairs, the eyelashes. They function as dust-catchers, and may be regarded as a natural model of the cow-catchers with which locomotives are equipped for traversing cattle-raising regions. When one passes through a swarm of mosquitoes, through rain, hail, or a sandstorm, the eyes are partly closed automatically, and the dust-catchers begin to function. Gnus and camels have the strongest eyelashes because they are exposed to sandstorms on the high plateaus and in the deserts of their native habi-

is performed by sebaceous glands, irrigation by the tear glands. Opening along the edge of each lid are from twenty to thirty minute sebaceous glands, called the Meibomian follicles. They terminate between the lashes and are compressed every time the lids close. The sebaceous secretion lubricates the edge of the lid and the lashes so that they will not become dry and brittle. When the mucous membrane of the lids is inflamed, the secretion of the glands is abnormally abundant and appears as yellow matter along the

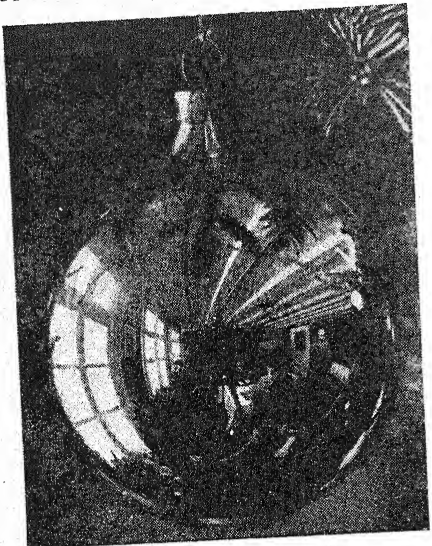


FIG. 370. *The outer world is reflected in the eye just as it is in this silver ball.*

edges of the lids, where it dries during the night, causing the lids to be stuck together in the morning.

Tears. Each eye has a lachrymal apparatus consisting of the tear gland, situated over the outer corner of the eye, the ducts which carry its secretion, the tears, to the upper eyelid, and the canals by which the tears are carried off from the front of the eye without running down over the face.

Every time the "windscreen-wiper" of the eye moves, it exerts suction on the openings of the tear ducts and withdraws some fluid from the tear gland, which irrigates the cornea and prevents it from drying up. A person cries not only when he is conscious of it, but all day long every time he blinks. Everyone knows that tears begin to flow when people laugh a great deal, because the spastically contracted muscles compress the glands. We laugh with tears. If the tear glands are removed, the cornea dries up and soon becomes "blind" and the unfortunate individual loses his vision. The tear fluid flows over the cornea and then along the edges of the lids to the inner corner of the eye. Here it is drained off by two tear canals, one of which opens by a small pore on each lachrymal papilla. The aperture of the lower canal can be seen readily by examining the eye with a mirror. The tear canals run inwards and open into the tear sac, from which the nasal duct proceeds to open into the nasal chamber, underneath the inferior turbinate.

Tears and Emotion

A professor once shouted at his crying wife: "Oh! Stop crying—it's nothing but physiological salt solution, anyway!" This is not true, however, for tears contain various valuable substances, among them a bactericidal substance which prevents the development of bacteria in the tear fluid.

Crying. All higher animals produce tear fluid to irrigate the cornea, but only man cries as an expression of emotional disturbance. Only a thinking and emotionally sensitive person cries. An infant yells, but it does not cry. Children cry when they learn to think and to feel. Crying is a process connected with speech; it is a substitute for speech, a protective mechanism whereby a speaking individual can still express his feelings even though he may be prevented from speaking. People, especially women and children, cry when they are unable to make themselves heard or to obtain justice with the weapons of speech and thought. When it has achieved nothing by means of logic, a speaking creature appeals to sympathy by crying. Cry-

ing is a reflex which has extended its field of action from the physiological to the moral realm—it is a new phenomenon in the developmental history of life.

Astigmatism. The cornea is not fashioned with mathematical precision like a photographic lens. The cornea is two per cent flatter in its horizontal than in its vertical diameter. Since the vertical diameter is most curved, the rays proceeding from the vertical line of a cross will be brought to a focus sooner than those on a horizontal line. If the eye is accommodated to see the vertical line distinctly, it will see the horizontal line indistinctly and vice versa. This weakness is called astigmatism, because the eye is unable to focus a number of points, or stigmata, distinctly at the same time. Figures 375 and 376 are two drawings by means of which one can determine to what degree one is astigmatic. A person whose cornea is equally curved in all directions sees all parts of the circular lines of Figure 375 with equal distinctness. If the curvatures of different diameters vary, the lines in one sector will appear grey and hazy while others will be sharply focused. If the book is moved back and forth the indistinct portions are shifted and the image flickers.

A Normal Defect

Approximately ninety per cent of all human beings have a slight " normal " or, as it is called, physiological astigmatism. If the degree of variation between the diameters is so great that the effort to correct the condition produces eye strain (headaches!) or indistinct vision, it becomes necessary to wear glasses which are curved more in one plane than in another, so as to correct the defect of the cornea.

The Lens. If one obtains an eye of a rabbit or a hare and removes the lens, one has a faithful replica of a human lens. The dimensions of the lens vary with age, increasing as the individual grows older. In early adult life the lens is about 0.32 inch wide and 0.16 inch thick, and resembles the magnifying glasses that we use.

Cells and Fibres

And now let us take the eye of an ox, which has a lens eight times as large, allowing its structure to be more easily studied. The lens is covered by a transparent capsule, the inner surface of which is lined with cells [Fig. 368 (a)]. At the anterior pole of the lens the cells are flat (b); the closer one comes to the lateral edge, the longer become the cells. They become elongated fibres that penetrate the interior of the lens, describing arcs in the process (c). The ends of the fibres meet with those of the opposite side in three sutures, forming a Y-figure on the anterior as well as on the posterior surfaces (d). The Y of the anterior

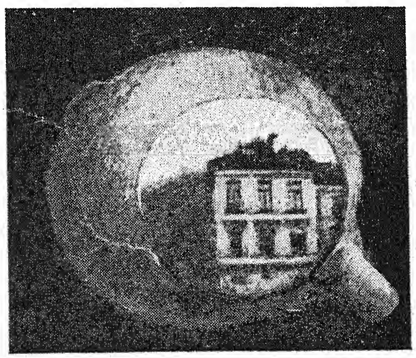


FIG. 371. *A photograph of an eye on the retina of which a house is reflected. Compare this picture with Fig. 370.*

surface is in an erect position, while the figure on the posterior surface is inverted.

Accommodation. Anyone who has occupied himself, even if only superficially, with photography knows the concept of focusing. If an object approaches too close to the camera, the reduced optical image formed by the lens is projected so far backward that it falls behind the photographic plate. Consequently, in order to receive the image the plate must be pushed backward, or, what amounts to the same thing, the lens must be advanced forward.

Focusing the Eye

Instead of increasing the distance between the lens and the plate, one can achieve the same result by another method. A lens is placed in front of the camera lens, thus increasing its refractive power to such a degree that the image formed falls upon the plate. In science the adjustment of the position of the eye for looking at objects at different near distances is called accommodation. There are eyes, among molluscs, for example, that accomplish this by elongating the eyeball, just as one pulls out the bellows of a camera; in other cases, as in fishes, the lens is moved back and forth by contraction and relaxation of an intra-ocular muscle attached to it. Accommodation in the mammalian eye is dependent upon the elastic properties of the lens. The lens increases the curvature of its surfaces and particularly of its anterior surface when the eye accommodates for vision of near objects.

The lens is surrounded by a strong and highly elastic capsule upon which it depends for the maintenance of its shape. By means of this capsule it is supported from a circular muscle called the ciliary body by a suspensory ligament [Fig. 372 (b); Fig. 378 (c)]. The ciliary body girdles the lens like a ring of Saturn and is the accommodation muscle [Fig. 372 (a); Fig. 378 (b)]. In the resting eye the fibres of this muscle ring are relaxed and the suspensory ligament is taut, thus flattening the surfaces of the lens, especially the anterior surface, since the ligament is attached a little in front of the edge [Fig. 378 (I)]. Distant images are then projected on the retina. If an object approaches closer to the eye than about eighteen feet, the image falls behind the retina. In order to push it forward, we accommodate. The ring muscle contracts and comes closer to the lens, the suspensory ligament slackens, and the elastic lens, relieved of this pull, follows its natural elasticity and bulges forward in the centre. The image which was behind the retina advances and is now sharply focused upon the photosensitive cells of the retina (II).

Distant and Near Vision

Distant vision (I) is effortless because the accommodation muscle is relaxed. For this reason we look up from our work when we wish to rest the eyes. Because of this fact we leave our close rooms that compel us to accommodate and go out into the open. It is also for the same reason that a holiday at the seaside or in the mountains, where we are not compelled to accommodate, is so restful. Near vision (II), as in reading, writing, sewing, demands accommodation and therefore produces a strain. The accommodation muscle is one of the most active muscles of the body and at the same

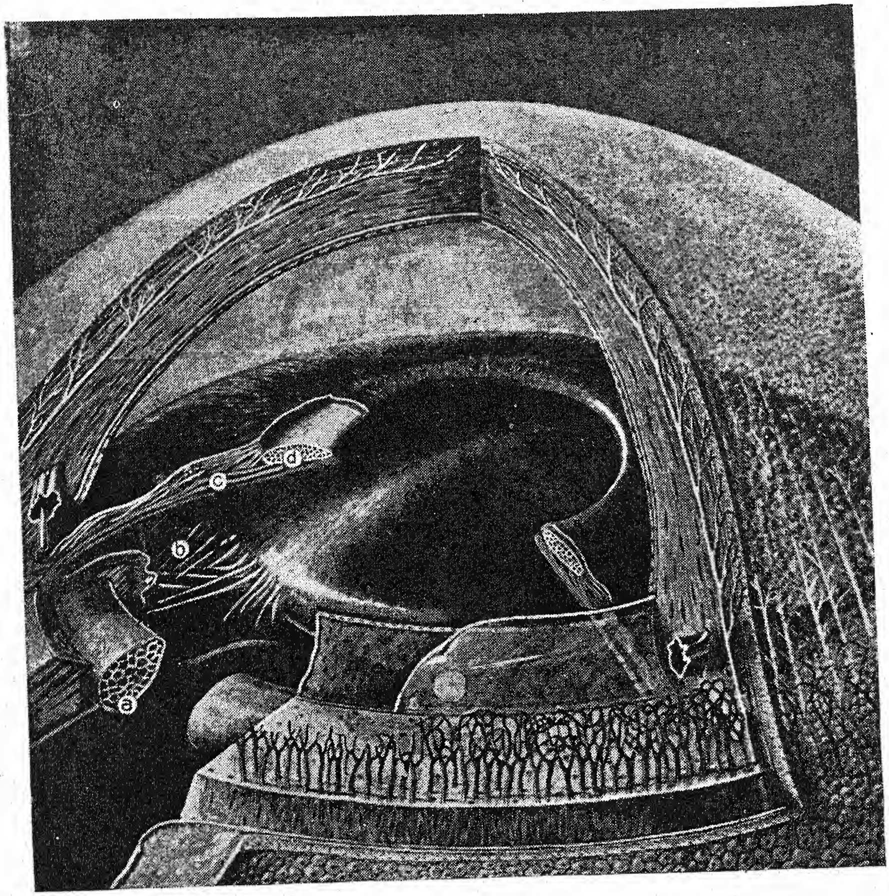


FIG. 372. *A view into the human eye: (a) the accommodation muscle, which tenses and relaxes the ligaments; (b) of the lens; (c) the longitudinal fibres of the iris, which dilate the pupil when they contract; (d) the circular fibres, which decrease the size of the pupil when they contract. Beneath the iris is the lens; above it is the dome of the cornea.*

time a precision instrument. It is consequently very sensitive, and there is no better way of determining slight degrees of fatigue than by testing the accommodation. When one grows tired while reading, the lines become indistinct and begin to merge because the tension of the accommodation muscle relaxes and the picture slides behind the retina, so to speak, as in a camera where the spring is defective. Then, as in all cases of muscular fatigue, we pull ourselves together, put the accommodation muscle under tension again, and are once more able to read for a time.

Some Accommodation Experiments. Stretch out one arm and fix your eyes on the tip of the index finger. Even with a normal eye this act requires an effort which cannot be maintained very long. If the fingertip approaches close to the tip

of the nose, the lens must relax more and more in order to obtain a distinct image; that is, the accommodation muscle contracts more and more and we feel this effort.

Hold up this book and look beyond the upper corner of the page into the distance. The eye is now rest, objects on the outside are seen distinctly while any spots on the window-pane or the patterns of a lace curtain are seen indistinctly [Fig. 378 (I)]. Remove the gaze to the spots on the window or the patterns of the curtain. These will now appear distinct, while the image of

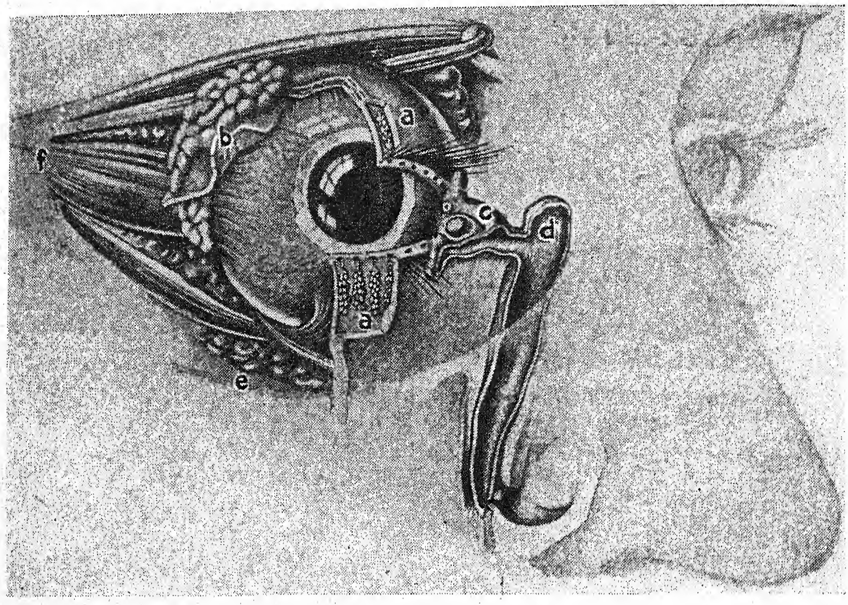


FIG. 373. *The structure of the eyelids and the tear apparatus. At (a) are the lids, with their sebaceous glands; (b) is the tear gland, with the "sieve" through which the tear fluid drips on to the eyeball; in the inner corner of the eyelids can be seen the two minute openings leading into the tear canal (c) and the tear sac (d), through which the tear fluid passes into the nose. The orbital fat (e) acts as a cushion for the eyeball as it rotates; the ocular muscles (f) move the eyeball and the eyelids.*

relaxed and accommodated for distant vision. The page number is indistinct. Now switch your attention to the page number; that is, put the accommodation muscle under tension. This requires a distinct effort. Such a rapid change cannot be carried out more than a dozen times in succession without the eyes beginning to feel tired.

Sit down at a window and look out. If the eyes are permitted to the outer world becomes hazy (II), since the camera, which is your eye, is now focused for near vision.

The Range and Amplitude of Accommodation. In the course of a lifetime, with advancing age, the lens loses its elasticity. The human eye is a camera whose ability to take photographs at close range decreases from year to year. For a child of six the near point—that is, the nearest point which the eye can see

clearly—is situated at 2.4 inches distant. At the age of thirty the near point has receded to 4 inches, at forty to 6 inches, and at fifty to 10 inches. The lens of a septuagenarian is hard and inelastic, and the near point has receded so far that the individual is no longer able to see things clearly at a practicable reading or working distance. When the condition has progressed to this stage it is termed presbyopia (from the Greek words *presbus*, old man; *ops*, the eye).

Presbyopia. As mentioned above, the lens grows harder with increasing age. Finally, the increasing hardness of the lens begins to prevent alterations of its curvature, so that the power of accommodation gradually diminishes. When the stage is reached where accommodation becomes impossible and the near point recedes to an impracticable distance, the presbyopic person must correct this condition by wearing lenses (glasses) which will perform the work of the accommodation mechanism and make possible near vision.

Types of Defective Vision

Hyperopia (Far - Sightedness). Three people are waiting for a bus marked S [Fig. 377]. A has a normal eye, B an eye that is too short, and C an eye which is too long. In the case of A, the retina (area with light shading) is situated within the intermediate space created by drawing the four parallel lines in Figure 377, while the retinas of B and C are in the anterior and posterior spaces respectively. In (I) a bus appears in the distance. The normal eye of A is so constructed that the parallel rays of light coming from the distance will unite to form an image on the retina when the lens is relaxed. He sees the S at a distance of about 200 feet without accommodating. The eye of B is too short, so that the optical image of the S is formed behind the retina. In order to focus it on the retina, he contracts the accommodation muscle. The lens increases its curvature, and the S moves forward on to the retina (in the direction of the arrow), so that B now perceives it quite distinctly.

Continual Adjustment

The condition in which the eye is relatively too short is called hyperopia, or commonly far-sightedness. Such a person can generally see distant objects satisfactorily, but he must accommodate strongly in order to focus on the retina the image which is located behind his excessively short eye. The eye of the hyperopic person is an eye which is never at rest, but which must always accommodate even for distant vision. In order to rest his eye and to see distant objects without any exertion, the hyperopic person must wear glasses that will correct this refractive defect.

Myopia (Near-Sightedness). C has an eye which is too long. Consequently the S is focused in front of his retina and appears indistinct. C is near-sighted, or myopic. A myopic person is one who is unable to see distant objects distinctly because of the excessive length of his eyeball. What can he do to focus the S on his retina? Nothing. Because if he accommodates, the image will move even farther forwards. The human eye has no mechanism to move optical images backwards, but this object can be attained by putting a bi-concave lens in front of the eye, so

that the S moves backwards in the direction indicated by the arrow.

In (II) the bus has come closer and the S in the eyes of the waiting individuals moves back (from the intermediate to the posterior space). A, who has normal vision, accommodates and the image passes from the posterior to the intermediate space and is focused upon the retina. date. For near vision the myopic individual has an advantage not only over the hyperope, but also over a person with normal vision. In order to read this book an individual with normal eyes must accommodate and consequently becomes fatigued after a while. The myope, however, reads without accommodating and without becoming fatigued, just as a per-

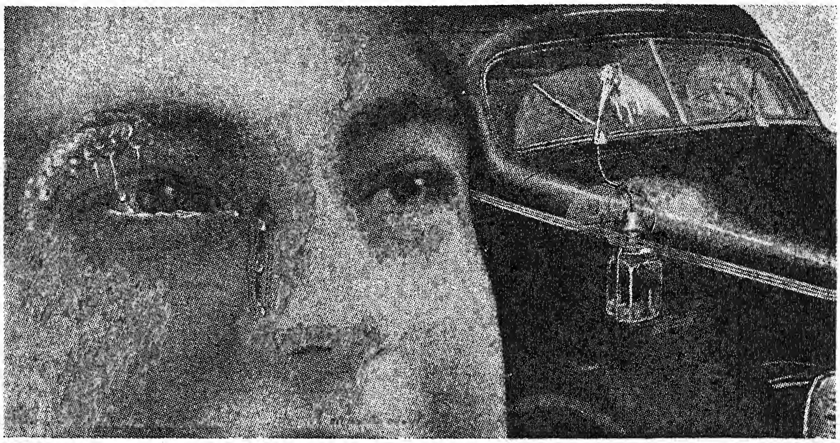


FIG. 374. *The tear glands and eyelid moisten and wipe the eyeball continually—as if the windscreen-wiper of a motor-car were combined with an automatic water spray.*

The hyperopic B does the same, but his eye is too short. Even with the greatest amount of accommodation he is unable to focus the image upon the retina. He is unable to read the sign S when it is near and must place a magnifying lens in front of his eye. However, in the excessively long eye of the myopic C the image of the S moves backward as the bus comes nearer until it is focused upon the retina. Without accommodating he sees the S distinctly. A person with normal eyes must accommodate for near vision. A far-sighted person is unable to see near objects even when he accommodates strongly. A near-sighted person sees things near him without having to accommodate. For near vision... son with normal vision can look into the distance without tiring, because at this visual distance his eye is at rest. In all fields where visual work and delicate manipulations are required the moderately near-sighted person is a superior rather than an inferior type. He does lack, however, the direct pleasure of distant vision. Until the introduction of spectacles about A.D. 1300 near-sighted people were cripples. Millions of people lived who never saw clouds, stars, mountains, or birds of passage. Not until the discovery of glass by the Phœnicians, and of the craft of lens-grinding many hundreds of years later, was it possible to correct visual disability and to convert

semi-blind invalids into useful members of human society.

Cataract. In some individuals the lens becomes opaque as they grow older, giving rise to the condition known as cataract. The pupil no longer appears black, but is grey. This opacity of the lens is the consequence of coagulation of the lens substance. The protein of the lens takes on a milky-white colour, just as egg-white does when it is boiled. Concussion, lightning stroke, occupation (e.g., glass-blower's cataract), poisons such as naphthol, and various diseases (e.g., diabetes) favour the onset of cataract. The removal of the opaque lens is one of the oldest surgical operations, and is mentioned in the famous Ebers papyrus of ancient Egypt. In order to compensate for the loss of the lens, the affected individual must wear a magnifying glass of similar refractive power.

The Vitreous Body. The vitreous body is a clear transparent colloid of semi-solid consistency filling the chamber of the eyeball behind the lens. It contains small opaque bodies causing the phenomenon known as "*mouches volantes*" ("flying mosquitoes") [Fig. 379]. If the head is raised and one looks at the sky, one sees what appear to be minute bodies floating in space outside the eye. However, they change their

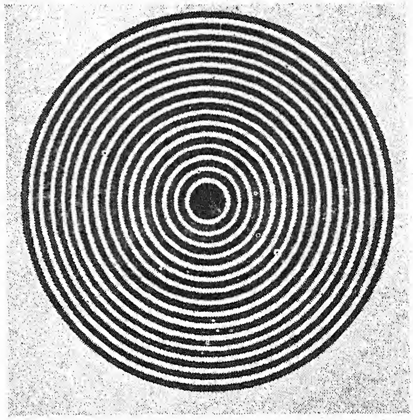


FIG. 375. *Are you astigmatic? (I). Take this book in both hands, shake it in different directions and then move it in small circles. If a fan-shaped figure moves over the picture, you are astigmatic—a condition which is rather normal than otherwise.*

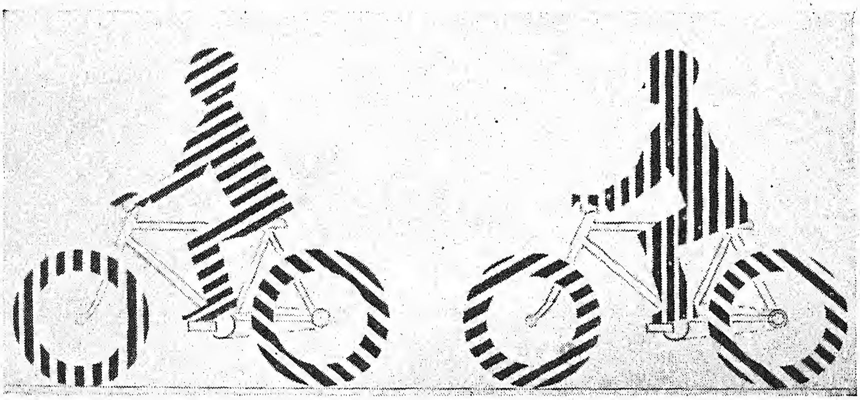


FIG. 376. *Are you astigmatic? (II). Look at this picture with your eyes partially closed. Shake the book in different directions and then move it in small circles. If, while you are doing this, some parts of the picture appear black and other parts grey, then your cornea has an uneven curvature—it is astigmatic.*

position when the position of the eye changes, by which fact their origin in the eye may be recognized.

The Iris. The posterior part of the inner surface of the eyeball is covered by the photosensitive layer, the retina, together with its accessory membranes, the pigment layer and the vascular tunic, or choroid. The retina encloses about three-quarters of the vitreous body. Anteriorly, however, the retina separates from it, giving rise to a free space, the anterior chamber. Here the retina ends in a free border, which because of its colouring is called the iris (or rainbow). Attached to the anterior surface of the ciliary body, it forms an extremely delicate diaphragm, stretching across the anterior part of the eye and provided with a circular opening, the pupil [Fig. 372 and Fig. 380].

The iris is the diaphragm of the ocular camera. The pupillary border of the iris is encircled by an annular band of muscle fibres, called the sphincter [Fig. 372 (d)]. Its position is analogous to that of the hub of a wheel. Other muscle fibres are arranged radially like the spokes of a wheel (c). When the ring fibres (d) contract, the pupil becomes smaller; when the spokes (c) become shorter, the pupil dilates. The muscle fibres of the iris are the only ones among all the muscles of the body that are directly photosensitive. Among the lower vertebrates the iris, when isolated by removal from the

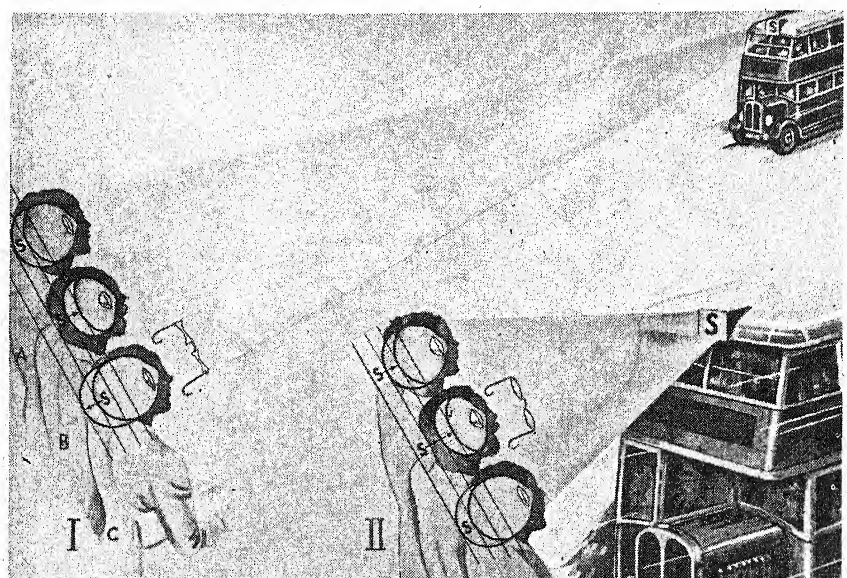


FIG. 377. *(I) Of these three men waiting for a bus, A has a normal eye, B an eye that is too short (far-sighted) and C an eye that is too long (near-sighted). Without any ocular adjustment, A sees the letter "S" on the bus distinctly when it is 200 feet away. With B, the image falls behind the retina, and he must accommodate in order to focus it upon the latter. In C's eye the image is formed in front of the retina, and he cannot see the bus distinctly without the aid of glasses. When the bus comes close (II), A sees it clearly, as also does C, but B requires spectacles in order to do so.*

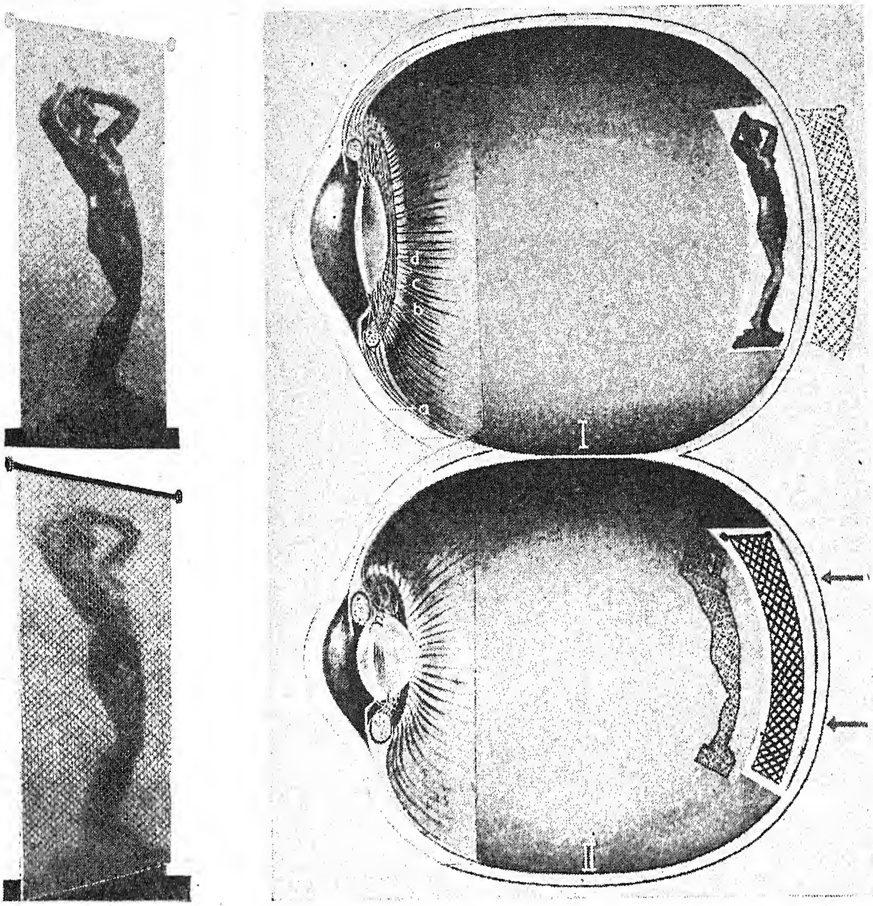


FIG. 378. *This illustration shows how the eye is automatically adjusted for near and distant vision. The cornea, or outer envelope of the eye is shown at (a); (b) is the ciliary body, or muscle of accommodation, which girdles the lens; (c) is the suspensory ligament, which joins the lens to the ciliary body; (d) is the lens. At the back of the eye is the retina. The statue on the left is situated immediately behind a net curtain. At (I) we see the adjustment of the lens for distant vision. The circular muscle (b) is relaxed. The supporting fibres (c) are tense and they pull on the lens (d) so that it is flattened. The flat lens provides sharply defined images of distant objects: therefore, the image of the statue falls upon the retina and is seen clearly. However, the image of the curtain, which is nearer to the eye, falls behind the retina and appears blurred. At (II) we see the lens as it appears when "accommodated" for near vision. The circular muscle of the eye has contracted, allowing the supporting fibres of the lens to relax. Accordingly, the natural elasticity of the lens causes it to become thicker and more curved. Owing to the increased curvature of the lens, images are not projected so far back in the eye, and therefore the image of the statue is focused now in front of the retina—instead of exactly upon it—and becomes blurred. But the image of the curtain falls upon the retina and is seen clearly*

body of the animal, still contracts on exposure to light. In the higher mammals this direct reaction is replaced by a reflex. The stimulus travels over complex paths deep into the brain and returns to the muscle fibres by way of special nerve tracts [Fig. 403]. Stand in front of a dimly illuminated mirror and flash a light into your eye, or place a person in a bright light, cover his eyes, and then suddenly let the light fall upon the opened eyes. In each case one observes the contraction of the pupil when light falls upon it. Since the path of the reflex is quite complex, it takes about a second for the reaction to appear. Amateurs who take flashlight photographs of people usually make the mistake of letting the flashlight go off in a darkened room. Because of accommodation to darkness, the pupils of the people being photographed are dilated, and since they react slowly to light, they are open at the moment when the flashlight picture is taken. As a result, in the photograph the eyes appear wide open as if the individuals were very surprised. Before letting the flashlight go off, the light in the room should be lit so that the people in it will be photographed with normally narrowed pupils. The human eye has an advantage over a camera in that it is equipped with an automatically functioning diaphragm.

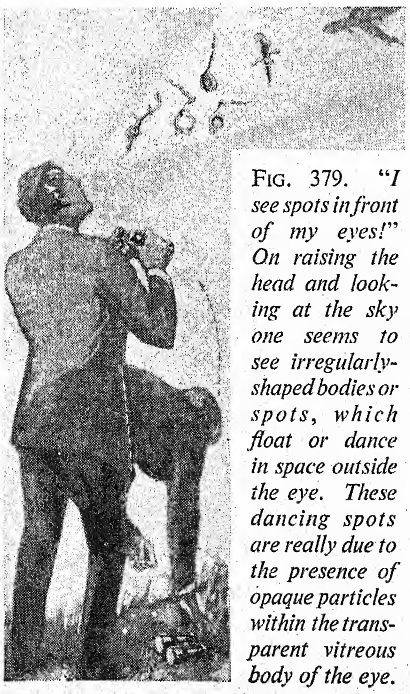


FIG. 379. *"I see spots in front of my eyes!" On raising the head and looking at the sky one seems to see irregularly-shaped bodies or spots, which float or dance in space outside the eye. These dancing spots are really due to the presence of opaque particles within the transparent vitreous body of the eye.*

Protective Device

Owing to its sensitivity to light, the iris protects the retina against excessive exposure to light, permitting only the amount of light required at the particular moment. If it is light outside, the pupil contracts; if it is dark, the pupil dilates so as to permit the eye to receive more light. Besides, as every amateur photographer knows, an optical image can be more sharply defined by screening off the edges of the lens. In order to examine something with our eyes, we screen the lens as far as possible; we lower the lids and blink, or hold a hand over the eyes to shut out some of the light, or if the light dazzles us, we may even look through the narrow spaces between the fingers.

Bring your eyes as close to this page as you can until the letters become indistinct. Now put your hand between the letters and your eyes, leaving narrow spaces between the fingers, and look at the letters through these spaces. By means of the screen created in this manner the letters again take on a distinct form. Persons with poor vision do not open their eyes very wide in order to see more, as one might ex-

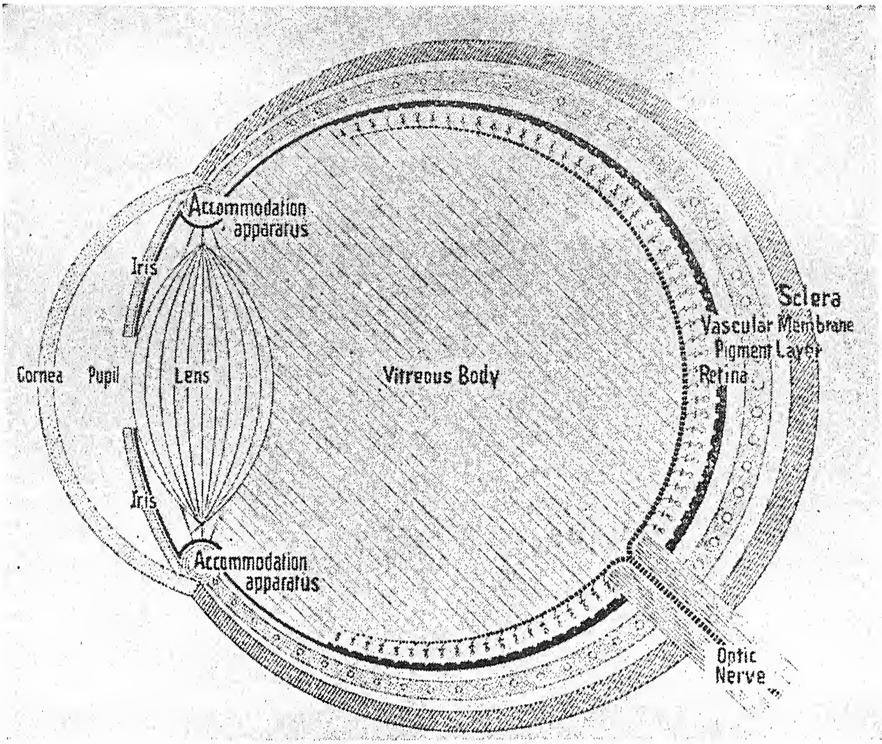


FIG. 380. *A diagrammatic view of a section through the human eye. Note the wide extent of the retina, embracing nearly three-quarters of the vitreous body.*

pect, but on the contrary they narrow them and blink because screening enables one to see more clearly. The scientific term for near-sightedness, myopia, is derived from the Greek word *muo,* " I close," and *ops,* " the eye," and refers to the habit near-sighted people develop of half-closing the lids in order to see more clearly. The combined lenses used in modern photographic apparatuses, the double anastigmatic types, etc., are far superior to the natural products, and the influence of screening is no longer so striking. However, if one takes a simple aplanatic lens, the value of screening becomes apparent. After dropping atropine into the eye the iris muscle is paralysed, the pupil is dilated, and the individual's vision is blurred, as shown in Figure 382.

The Pupil. The dilatation of the pupil is effected by fibres of the sympathetic system, its contraction by vagus fibres. Everything which excites the sympathetic system (joy, passion, sex excitement) dilates the pupil; anything that stimulates the vagus (fear, melancholy, vexation) contracts it.

Nicotine and morphine contract the pupil because they paralyse the sympathetic, and it is these pinpoint pupils that betray the morphine addict to the doctor from whom he is trying to obtain a prescription by means of some trumped-up story.

Atropine dilates the pupil (ten minutes after instillation—a half-hour after administration by mouth), $\frac{1}{200000}$ of a gramme sufficing to produce a definite dilatation. Scopolamine, the poison of the solanaceous or nightshade plants, exerts an effect five times more powerful.

Absent Reflex

Pupillary Paralysis. In the disease known as tabes dorsalis, as well as in various other diseases of the nervous system, the pupillary reflex disappears, giving rise to a fixed pupil, which neither dilates in the dark nor contracts when light falls upon it.

Eye Colour. In order to increase its protection against light, the fibres of the iris are pigmented. The posterior portion of the iris is heavily pigmented, while the anterior portion, at least in the white races of mankind, is relatively free from pigment at birth. As this latter portion is very transparent, and absorbs the long red and yellow light waves as they pass through it, the light re-

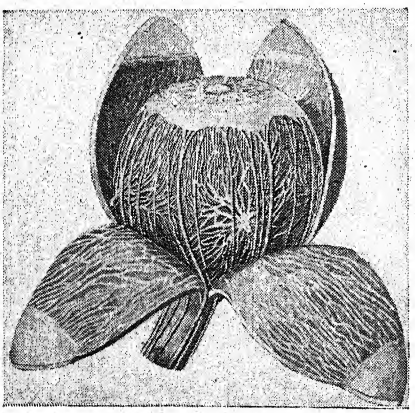


FIG. 381. *Blood vessels of the eye. Since the eye is a very active organ—and, being exposed, must also be protected against cold—it has a plentiful blood supply.*

flected from the deep pigmented portion appears blue, in the same way as does the sky or the veins immediately under a delicately transparent skin. If pigment does not develop subsequently in the anterior portion, the iris retains a blue colour through adult life. On the other hand, if much pigment develops in the anterior portion, the iris becomes brown. The pigment is yellow, or of lighter or darker brown.

The Retina. The camera obscura of the eye is lined with a photosensitive layer, the retina. The term is derived from the Latin word *rete*, meaning a net, because the retina appears to enclose the vitreous body, just as a net encloses the catch. Figure 383 is a diagrammatic representation of its structure, while Figure 385 gives a detailed view of the monumental structure of this light-wave apparatus.

Nerves of Seeing

Viewed anatomically, the retina is an advanced part of the brain and consequently exhibits a corresponding structure [Fig. 383]. It consists of nerve fibres that emerge from the depths of the brain in a bundle, the optic nerve, and end in a system of neurons, (1) to (5), connected in series. The first neuron is the cell of the optic-nerve fibre (1). This is followed by short internuncial cells (2), and these in turn are connected to cone-shaped nerve cells, called cones (3). Or the optic nerve cells (1) are connected to long internuncial cells (4) and these again to rod-shaped nerve cells, the rods of the retina (5). The rods and cones are the actual photosensitive elements of the retina, the visual cells. They are shaped like matchsticks, and one can find no better model of

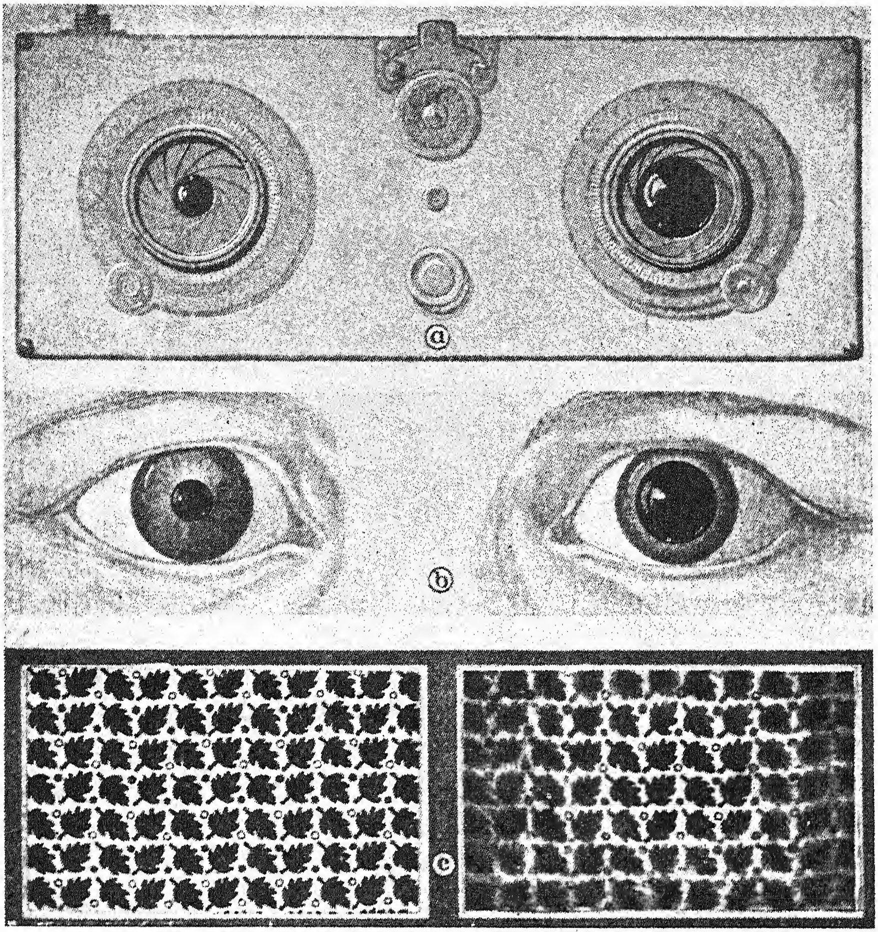


FIG. 382. *The iris diaphragm of a camera (a) and that of the eye (b) are similar in structure and perform a similar function—that is, to dilate and contract the opening of the lens. At (c) is a photograph (Left) taken with the diaphragm of the camera in use and (Right) a photograph taken without the diaphragm.*

the retina than a full matchbox. Imagine a table covered with upright matchboxes, so that the tips of the matches point upwards, and one has a picture of the retina magnified a million times.

Picture Reproduction in the Eye, in Printing, and in Television. It is naturally no accident that the retinal cells assumed the form we have described, and are so small that, next to blood cells and sperm cells, they are the smallest in the body. In the retina, just as in a full matchbox, as many individual units as possible are located next to one another within a limited space; thus they provide as fine a "grain" as possible for the recording of the picture. For the reception of an image the eye uses the same method as is employed in printing

and television—namely, the breaking up of the image into discrete points. If one wants to print a picture or to send it by television, it is first sent through a fine sieve, or screen, and broken up into minute points. Look at the world through a sieve, or through a lace curtain; it dissolves into individual points. The finer the holes of the sieve, the finer and more numerous are the image points, and the finer and more undisturbed does the picture appear. In Figure 384 one sees the head of Nefertiti photographed through a coarse screen (25 dots per inch); the other pictures in this book are printed with approximately 100 dots per inch. The eye, however, "prints" with 8,750 points per inch. The entire retina contains approximately 50 million points. The human eye is far from being the finest visual apparatus of the animal kingdom. In the eyes of small birds the visual cells are four times closer, in mice and rats ten times closer, than in human eyes, because small animals are generally much nearer to the very small objects they are concerned with, and consequently have to have finer vision than man, whose eyes are generally several feet from the object.

Visual Acuity. The fineness of the ocular screen is characterized as its visual acuity. In order for two separate points to be perceived, they must stimulate two visual elements that are separated by an unstimulated one. In the human retina the distance between the points must exceed 0.003 millimetre, and the minimum visual angle—that is, the smallest angle which two rays of light entering the eye may form in order that the points from which

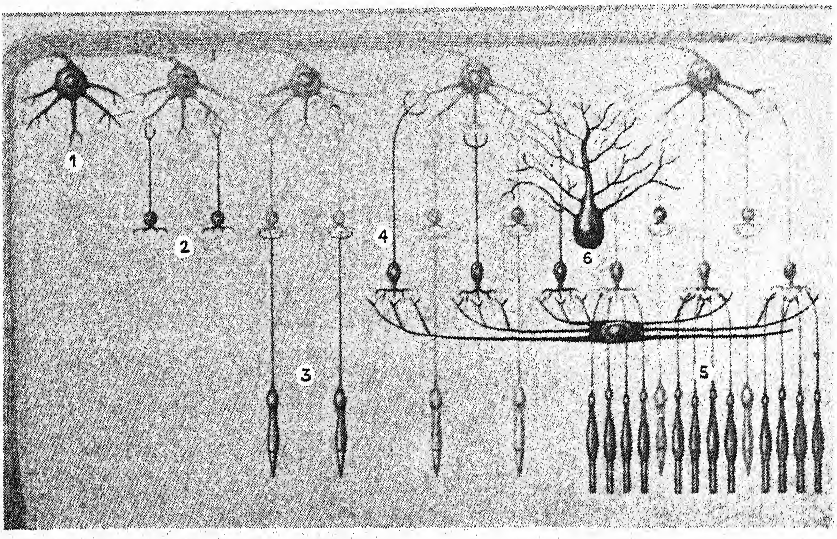


FIG. 383. *A diagram of the retina. The million photosensitive cells (3, 5) of the retina break down images of the external world into numerous point-images. Through the medium of internuncial cells (2, 4, 6), which are still obscure, the point-images give rise to electrical currents, which are sent by the large optic nerve cells (1) through the optic nerve tract into the brain. (Compare Figures 295 and 296.)*

they emanate may be discriminated as separate — must not be smaller than 1 minute of arc—that is, $\frac{1}{5400}$ of a right angle. This fine limit suffices for the human eye, which sees objects at relatively great distances. Look at Figure 384. Seen at arm's length, the distance at which the picture was intended to be viewed, it appears to present a uniform surface. On bringing it closer to the eye, however, one recognizes that it consists of dots, the screen "grain." This "grain" is seen even more distinctly when a magnifying glass is used. Conversely, if the picture of Nefertiti, which is composed of coarse dots, is removed to a distance of about six feet, the dots will coalesce to form a uniform surface. Our picture of the world is composed of such screen dots, which correspond to the tips of the rods and cones distributed closely over the retina.

Pictures Made of Dots

Man and nature employ what is substantially the same method for reproducing and printing pictures. In order to print a so-called "halftone" picture it is first of all photographed through a "screen," perforated with minute apertures like a fine sieve. According to the amount of light and dark of the various parts of the picture, larger or smaller dots are produced in the "holes" of the screen. The coarse dots coalesce, producing the dense parts of the picture, while the smaller ones remain farther apart, producing the lighter parts of the picture. If these dots are printed so lightly that they merge, they mingle with the white of the paper, giving an appearance of graduated tones of grey. This effect can be obtained with Figure 384 by removing the picture to a distance of six or seven feet from the eyes. If all the half-tone illustrations in this book were magnified four times, they would all be seen to consist of white and black dots, like the head of Nefertiti in Figure 384.

In the eye, the image that is projected upon the retina by the lens is likewise broken up into tiny dots by the rods and cones of the retina, because each cell responds to a single dot only, and that no larger than itself. The total stimulus image is composed of cell points stimulated to a greater or less degree. Strongly stimulated cells transmit light impressions while weakly stimulated cells report dark impressions. The image impression in the visual sphere

FIG. 384. *This picture is composed of dots; it has been photographed through a screen. In a similar manner, the rods and cones of the retina "break up" visual impressions into numerous tiny point stimuli, which are re-assembled in the brain and seen as a complete image.*

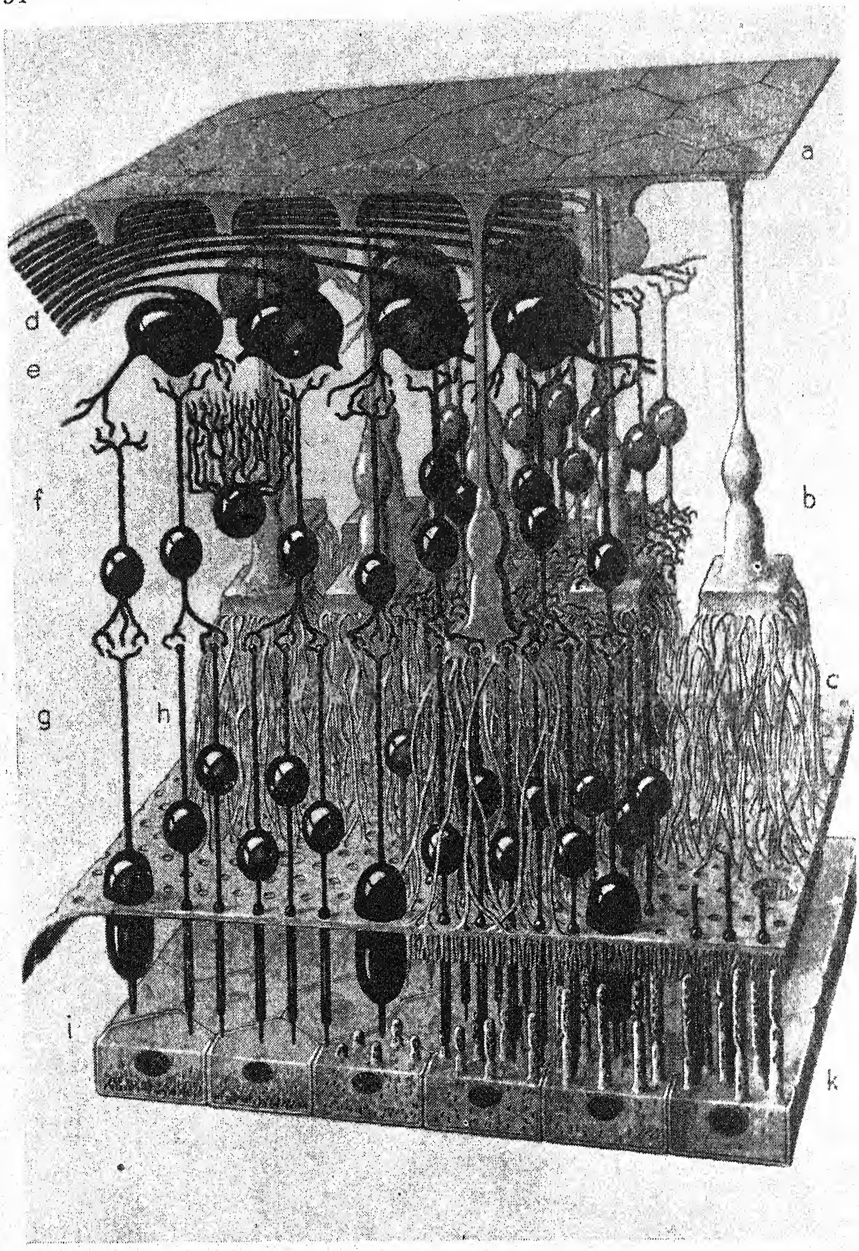


FIG. 385. *The television apparatus of the retina, like that of a broadcasting station, transforms optical images into electrical currents. Above are shown the supporting framework (a, b, c), the nerve cables (d), transmitting cells (e), and connecting cells (f); (g) and (h) are the photosensitive cones and rods, which are the actual visual cells; (i) and (k) indicate the layer of pigmented cells forming the protective base.*

of the cerebral cortex is composed of the sum of these point stimuli. If a retinal image were to be magnified six hundred times, one would see that it consists of points or dots similar to those of a half-tone engraving.

The Visual Cells

Rods and Cones. Figure 385 shows the ingenious arrangement of the nerve cells in the retina. Above is a roof composed of tile-like cells (a); below, a sieve-like, perforated floor (c); the two are united by columnar cells. The upper parts of these cells support the roof; the lower portions with their tufts of fibres (b) form the sieve-like plate. In accordance with the character of the retina as a part of the brain, these columnar cells are glia cells, which serve not only for support, but also to transport nutritive materials from the blood vessels to the nerve cells. The nerve fibres which come from the brain as the optic nerve run along the roof (d). They terminate in the large optic-nerve cells (e) that hang from the roof like hanging lamps or suspended flower-pots. The rods (h) and cones (g) are inserted into the perforated plate of the floor like pens and pencils in their stands. Originally all visual cells were rod-shaped. The eyes of the lower animals, and of all twilight and nocturnal animals that have to get along with indistinct visual impressions, contain only rods. With the improvement and refinement of vision, rods were transformed into cones. The cones are more efficient. Highly mobile animals possessing great visual acuity, such as birds, possess only cones. In man the cells in the centre of the retina, in the central optic pit (*fovea centralis*) [Fig. 386 (a)] have been transformed into cones. The farther

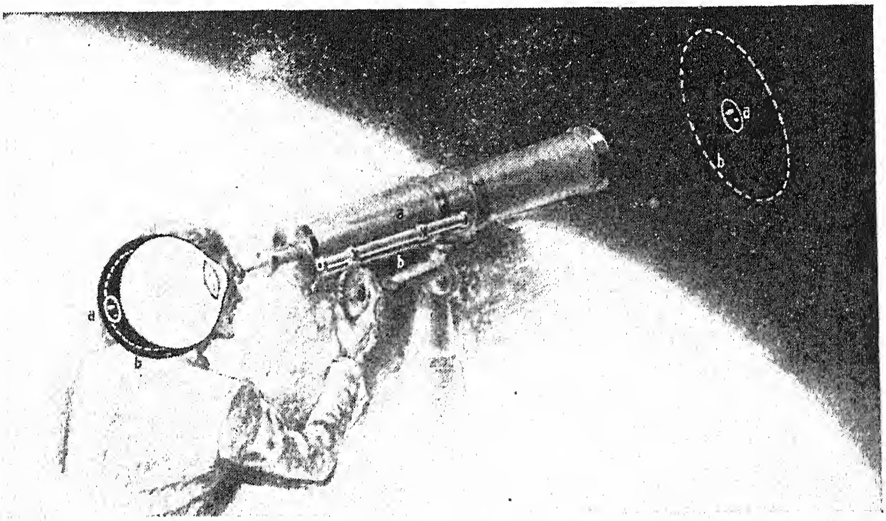


FIG. 386. *The eye, like an astronomical telescope, consists of a main instrument of great power but with a small visual field (a-a-a), combined with a smaller and less powerful instrument having a large visual field (b-b-b). The latter instrument is employed to discover the object; it is a finder like the view-finder in a small camera.*

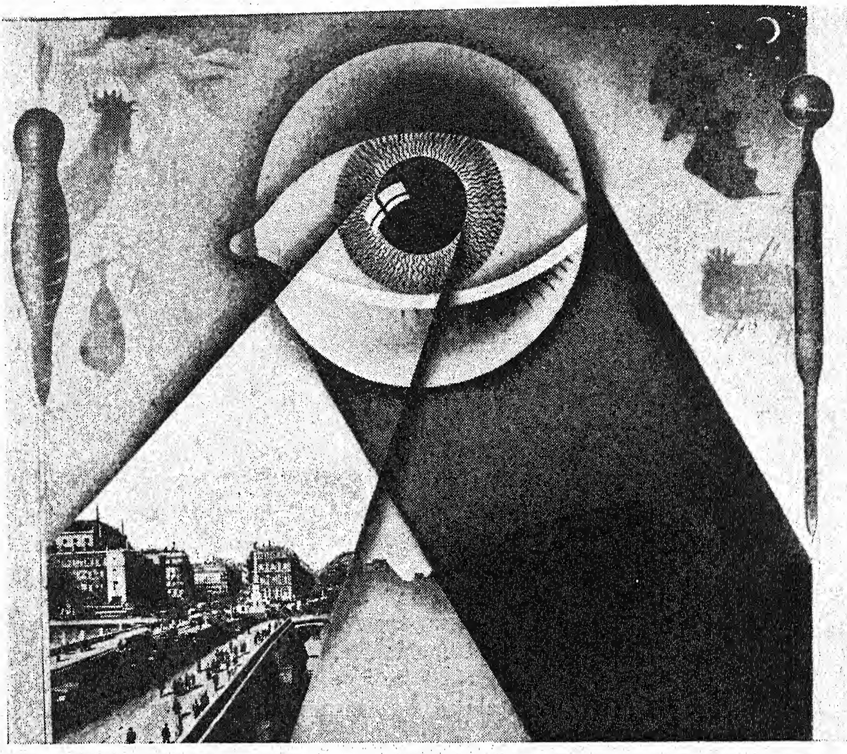


FIG. 387. *The human eye is a camera for both day and night photography. The retinal cones (Left) operate in daylight, producing sharply defined, fully coloured pictures. Those creatures, such as chickens, whose eyes have only cones can see in daylight only and go to sleep at sunset. The rods (Right) are highly sensitive to dim light, producing indistinct, colourless pictures. Nocturnal animals, such as owls and bats, have only rods in their retina, and they shun bright light, which is too strong for their highly sensitive eyes. The human eye contains both rods and cones; it has a central colour-sensitive area for daylight vision and a peripheral apparatus for nocturnal vision.*

one passes from this point to the periphery, the fewer become the cones, and in the periphery one finds only rods (b). By means of this separation man has acquired a double eye: a central eye composed of cones, and a peripheral eye consisting of rods. Both parts have their advantages.

Finder and Observer. When an astronomer wants to observe an object in the heavens with a large instrument, he faces the extremely difficult task of finding it, because a telescope with a high magnification surveys only a very small portion of the sky. Since the stars appear to move, owing to the rotation of the earth, and are only present for seconds in the visual field of the telescope, it is almost impossible to bring a definite point into the visual field of a massive instrument. This can only be accomplished by means of a finder [Fig. 386 (b)]. A finder is a telescope with a low power of

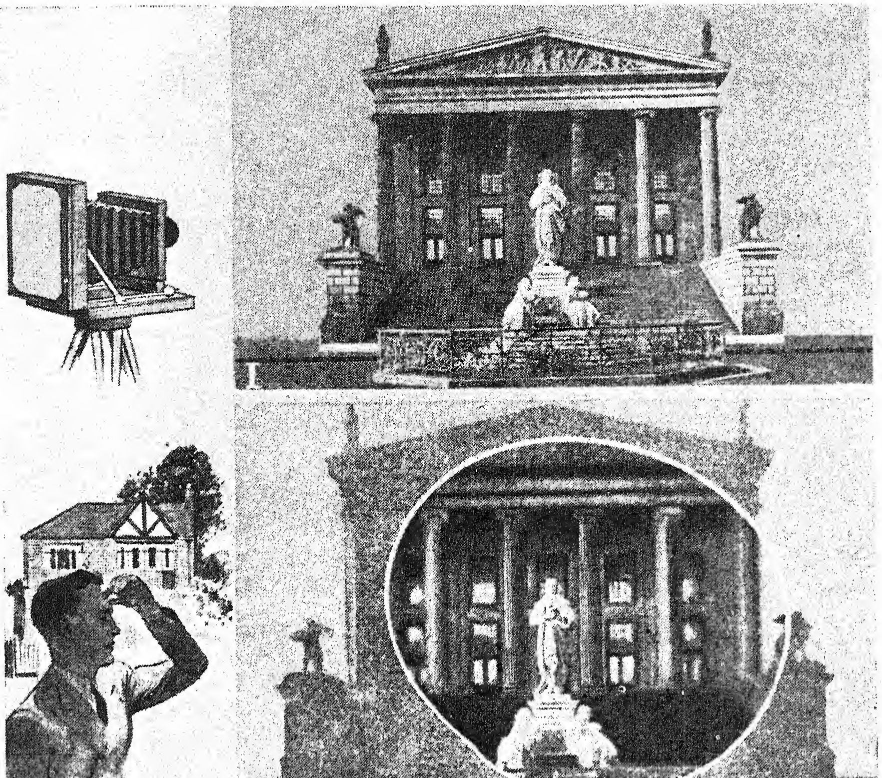


FIG. 388. *We imagine that we see the world like (I) but it is a camera's view; (II) shows how the eye sees in daylight—centre of the visual field clear, periphery blurred. At night (III) the centre of the field is, however, less clear than the edges.*

magnification but a large visual field, by means of which an object can easily be found. The finder is automatically connected with the large instrument. If an object is seen in the centre of the finder, it is also visible in the large telescope. The peripheral eye is a finder of low

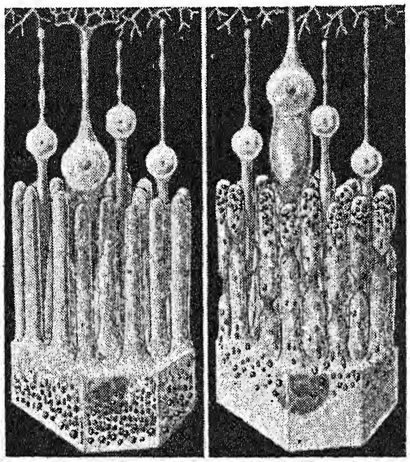


FIG. 389. *The pigment screen. The photosensitive cells of the retina are surrounded by the plasma tubes of the pigment cells. Under the influence of light the brown pigment granules rise within the tubes and screen off the cells. (See also lower right-hand corner of Fig. 385.)*

visual acuity, but with a large visual field; the central eye is an observation instrument with a restricted visual field, but possessing great visual acuity. The rods of the periphery see poorly, but they find objects easily because they extend over a large area. Once the object has been found by the rods, the observer's eye is now directed upon it; that is, we focus the central optic pit and regard the object with the keen instrument of the cone apparatus.

The difference in the accomplishments of the central optic pit and the periphery of the retina is explained by the differing anatomical structure of the two areas of the retina. The cones of the retinal pit are attached individually to the nervous system, as one recognizes from Figure 383 (3) and Figure 385 (g). Thus each cell transmits to the brain the sharp image of an isolated point. The cones are point-observers. The rods, on the other hand, are united in groups, as shown in Figure 383 (5) and Figure 385 (h). Their internuncial cells receive group stimuli instead of individual stimuli.

Man's Double Eye

Owing to this group formation the periphery of the retina is more sensitive to light, since the stimulation of all the rods attached to one internuncial cell forms one common stimulus in it. But since the stimulation of different cells forms a collective impression, we do not see points with the periphery of the retina, but rather surfaces; that is, we do not see distinctly, but in a blurred way. The periphery of the retina works with a coarse screen. The central pit of the retina is our daylight eye; the retinal periphery is our nocturnal or twilight eye.

Owing to this bipartite development of the retina, man has a double eye, one for daylight vision, the other for twilight [Fig. 387]. Pronounced daytime animals, such as chickens or canaries, have only cones in the retina and are night-blind: pronounced nocturnal animals, such as owls and bats, have only rods, which are indeed even more photosensitive than those of man, because they are collected in larger groups. The eye of a hooded crow contains 40 times as many association cells as that of man, while the eye of a cat

contains 2,000 times as many, and that of a dolphin, which hunts in the water at night, has 7,000 times as many of these cells.

How Do We See the World? Figure 388 (I) is a photographic view of a building. We believe that we see the world thus, as it appears in the photograph. But we are deceiving ourselves. That is how the camera sees it, which with its box form and flat posterior wall is well constructed to do so. The eye, however, is a hollow sphere: consequently its projection surface is curved and produces pictures such as that at (II). Only the central portion is distinct; laterally the picture is blurred. The area of distinct vision is circumscribed and presents a more or less circular form. Take an empty egg-shell and mount a cheap aplanatic lens in the opening. Neither this model nor the pictures taken with it will win any prizes in a contest, yet it is a model of a human eye, a miracle of nature, but a very questionable construction from a technical point of view. We overlook its defects because, in the first place, we see with two eyes, and secondly, owing to the constant movements of the eyes, the visual field is illuminated as though with a searchlight.

Twilight Vision

Daylight Eyes and Nocturnal Eyes. If one stands before the same building in the twilight, a very different visual impression is obtained (III). In the twilight the centre of the visual field sees less than the periphery because the cones are less photosensitive than the rods. Twilight vision is characterized by the paradoxical statement that we do not see what we look at, and we may not look at what we see, because if we do, it will vanish. Since the periphery of the retina is better able to perceive moving objects than resting ones, in the twilight one sees best that which moves in the periphery of the visual field—the eye is focused in this way as a protection against nocturnal enemies. During the day one sees chiefly with the central part of the retina. Spatially, the central

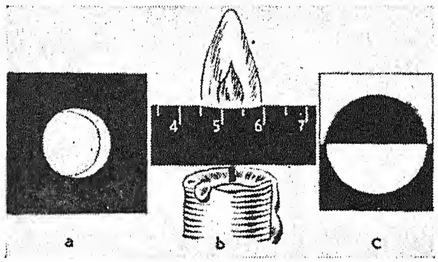


FIG. 390. *Irradiation. Against a dark background, light surfaces appear larger than do dark surfaces of equal size against a light background. The crescent (a) is not larger than the circle; the lower half of the circle (c) is no larger than the upper half. A ruler viewed against a candle flame (b) appears to be indented.*

visual field is restricted, but everything contained in it is seen clearly, distinctly, and in all its colour. The spatial limitation is compensated by constant movements of the eyes. At night one sees chiefly with the periphery of the retina. In the centre of the visual field one sees little or nothing, while peripheral vision is indistinct and colourless. Yet one surveys a large area and perceives movement best in the lateral portions of the visual field. One can easily convince oneself of this paradoxical and consequently apparently unbelievable fact. Attach two postage stamps to a wall about ten inches apart so that the light, gum-covered backs face the observer. Then

darken the room until the stamps can just about be perceived. If one eye is now fixed on one of the stamps, it will disappear while the other stamp remains visible at the periphery of the visual field. Should the observer's glance now be directed

FIG. 391. *The negative after-image. Fix your gaze for at least two minutes on the cross and then quickly place a blank sheet of white paper over the illustration. A positive image will appear in place of the negative one printed here. Repeat the experiment with paper of various colours.*

upon the perceived stamp, it will disappear and its neighbour will become visible.

The Peripheral Phenomenon. This phenomenon is known to astronomers as the peripheral phenomenon. They know that objects of very faint luminosity appear at the edge of the visual field when they look through a telescope. When the telescope is focused so that the objects will appear in the centre of the visual field, they vanish. This peripheral phenomenon is the reason why people see ghosts. In the twilight things are observed laterally which disappear when one turns round and looks for them; they reappear as soon as one turns away again — these are the ghosts that haunt people!

The Visual Purple. Since they are organs of nocturnal vision, the rod cells are sensitized for this purpose by a special pigment, the visual purple. When viewed in the light of day, the retina of an animal killed in the dark presents a reddish appearance. It loses its colour rapidly, since light bleaches the visual purple.

Adaptation to Dark. Unless they have been sensitized by the visual purple, the rods are unable to see anything in the dark. Since the visual purple is first formed in the eye after the disappearance of light, it is some time before one can see in the dark. On entering a dark room one perceives nothing at first. Gradually objects begin to appear out of the darkness. Every amateur photographer who has worked in an improvised dark room is acquainted with the following experience. At first one believes that the room is entirely dark, but after a quarter of an hour one discovers that there are cracks present which let in some light. After fifteen minutes an abundance of visual purple has been produced, and the photosensitivity of the eye rises to 2,000 times its initial value.

Night Blindness. If an individual loses the ability to form visual purple, he becomes night-blind.

Vitamin A is necessary for the formation of visual purple, so that night blindness, or nyctalopia, as it is called scientifically, appears in consequence of avitaminosis, and disappears promptly when the body receives vitamin A. Animals whose eyes have no rods, such as chickens, song-birds, snakes, and lizards, are naturally night-blind and consequently go to sleep with the appearance of twilight. Conversely, animals with a rod apparatus such as horses, cats, and bats are more or less day-blind and see well when it becomes dark [Fig. 387].

The Nocturnal Expansion of the Visual Field. By the sensitization of the retina, the peripheral portions of the retina which cannot see during the day without this sensitization become capable of visual activity. As a result the visual field expands to include this "peripheral twilight zone." In the dark one does not see as well as when it is light, but one does see more. Laterally one can look farther backward than in the daytime, the visual field being expanded by the addition of the crescentic zone shown in Figure 388 (III).

The Daylight Pigment. The rods, as the nocturnal cells of the eye, require a sensitizer in order to become photosensitive. Conversely, the cones, as day cells, require a protective substance against the effect of dazzling light. The posterior surface of the retina is covered with hexagonal cells, containing a fluid protoplasm filled with dark pigment granules [Fig. 385 (i-k)]. When light enters the eye, the protoplasm containing the pigment streams anteriorly along the visual cells, surrounding them like a sheath [Fig. 389]. If one steps into a brightly illuminated space, one is dazzled at first because the strong light irradiates from one cell to the next. However, in the course of several minutes the pigment migrates between the cells, separating them from one another, and the eye has, as we say, adapted itself to light. The light adaptation of the eye takes place much more rapidly than its dark adaptation.

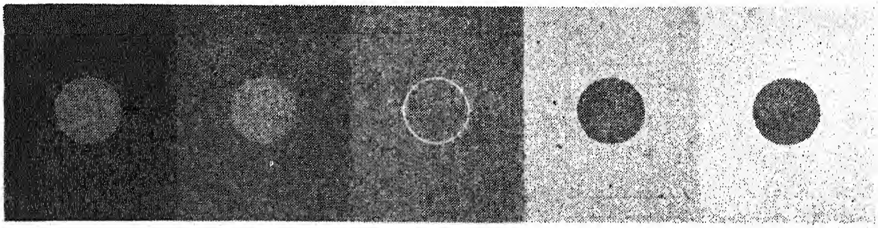


FIG. 392. *Which disk is the lightest in shade? Cover the picture with a strip of paper which permits only the disks to be seen: they will be found to be of the same shade. Grey tones appear darker on a light background, and lighter on a dark background.*

Irradiation. When a strong beam of light enters the eye, not only are those cells upon which the light impinges stimulated, but the excitation also affects the neighbouring cells, somewhat like the process of electrical induction. As a result the object appears larger than it actually is. This phenomenon is especially noticeable in the region of the rods, because they are very photosensitive

and, in addition, are united in groups. Even if only a single rod at the edge of such a group is stimulated, still the connecting cell will transmit an impulse as great as if the entire group had been stimulated by the light. Secondly, the human lens, which is not as refined an instrument as the lens of a good camera, since it is only a simple aplanatic lens, exhibits the condition known as spherical aberration. The stronger the light, the more noticeable is this phenomenon. Thirdly, one habitually tends to over-estimate the size of large, striking objects, while, on the other hand, dark, unassuming things are under-estimated. These three causes, physiological, physical, and psychological, explain the phenomenon of irradiation. We regard light objects as larger than dark ones of equal size. When the narrow lunar crescent is visible in the sky, the shining part of the moon appears to be one-fifth larger than the dull non-illuminated portion [Fig. 390 (a)]. If one holds a ruler in front of a candle flame or an incandescent bulb, it will appear curved in the area of radiation, because the stimulation of the retinal cells spreads beyond the actually affected area (b). In white clothes people appear larger, especially when they are seen against a dark background. A white dove appears larger than a black one. Manufacturers make use of this knowledge by employing only light colours for the cans, tubes, and boxes in which they pack their products.

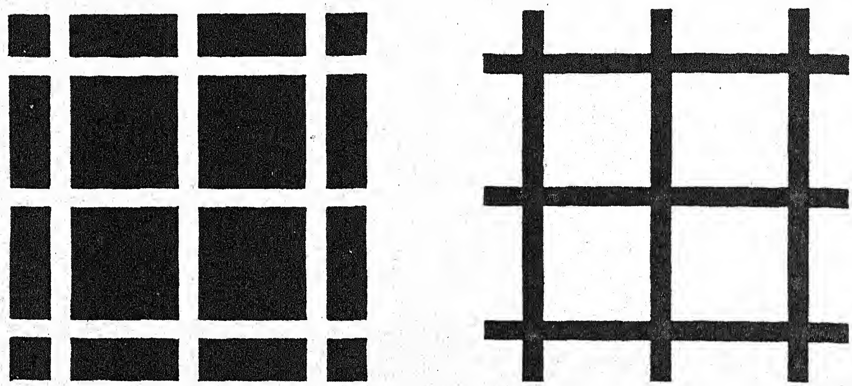


FIG. 393. *Look at these two patterns in turn: a grey spot appears at each of the places where the white or black bars intersect. But if any one of these crossings is regarded intently, i.e. with the fovea, or central cone apparatus of the retina, the grey spot vanishes, and that part of the bar becomes white or black once more. The other grey spots remain, owing to contrast, which affects only the periphery of the retina.*

The Positive After-Image. A stimulus requires a certain time to produce a full effect. If a finger is passed rapidly through a flame, the heat is hardly noticed. Similarly, sensations take a little while to disappear; they persist for some time after the withdrawal of the stimulus. The fact that visual activity continues after stimulation of the retina has ceased has been known from very early times. Aristotle was acquainted with this phenomenon. After-images are visual sensations

which remain after the stimulus has been removed. They are best seen after looking at bright objects. There are two kinds of after-images, positive and negative. In the case of black and white stimuli, such as Figure 391, the terms correspond to those used in photography. In the positive after-image the light areas appear light and the black ones dark; in the negative image the appearance is reversed. When coloured lights are used, positive after-images are always the same colour as the object looked at. Negative after-images exhibit the colours which are complementary to those at which the observer has been looking. If one looks for a moment at a burning match and then closes one's eyes, one perceives a positive after-image of the flame. The phenomenon is probably due to the persistence in the visual cells of the chemical process initiated by the stimulus, after the stimulus itself has been withdrawn.

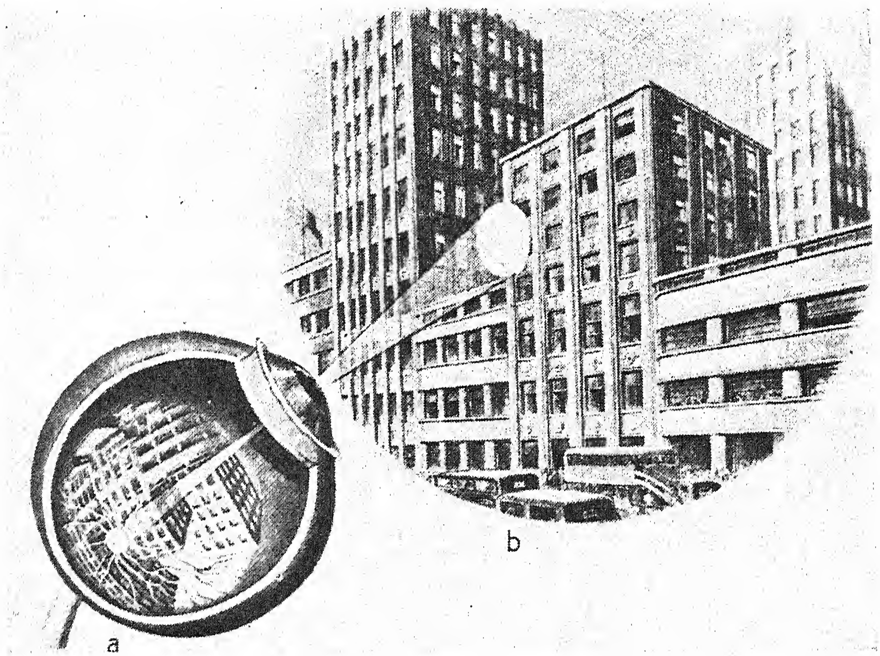


FIG. 394. *This picture explains the cause of the "blind spot." The optic disk, or papilla, which is the point where the optic nerve enters the retina, contains no visual cells and is consequently blind (a). Therefore the visual field also contains a "blind spot" (b).*

The Negative After-Image. If stimulation is continued so long that the visual cells become fatigued, a negative after-image appears. Thus while positive and negative after-images are opposed in appearance, there is no discontinuity between them, and one may merge into the other. The nature of the after-image produced depends on the intensity of the original stimulus and the occurrence of succeeding stimuli. A single stimulus of medium intensity produces a positive after-image, but when a second stimulus falls upon

the same area of the retina after the visual cells have become fatigued, a negative image is produced. Thus if a coloured light is regarded for thirty to forty seconds and the gaze is then directed upon a white surface, an induced negative after-image, consisting of a spot tinged with complementary colours, is produced. This phenomenon is also known as successive contrast.

We are all acquainted with this contrast phenomenon. If one looks at the setting sun, the retina is soon fatigued, "paralysed," by the strong stimulus, so that after removing one's gaze from it, all sorts of contrasting after-images of the sun are seen. The colours of these after-images depend on the colour of the sun and that of the surface upon which the gaze is directed. The two patterns in Figure 393 are very suitable for producing after-images.

An Optical Illusion

Contrast. In looking at the two patterns of Figure 393, one is disturbed by a remarkable sensation. At the points of intersection the white lines appear darker and the dark lines lighter, as if they were covered with grey patches. If one looks closely at one of these patches, it disappears. The others, however, continue to persist. Thus this is evidently a peripheral phenomenon —that is, a phenomenon perceived by the rod cells of the retinal periphery, but not by the cones of the central fovea. In the case of this optical illusion we are dealing with a contrast effect. Contrast is a term used in optics to describe the fact that differences of luminosity and colour appear accentuated when placed in juxtaposition. The five disks in Figure 392 are all equally grey. This becomes evident when Figure 392 is covered by a strip of paper in which holes have been cut so that only the disks are visible. It is obvious that a patch of grey appears darker on a white background than it does on a black background. Where they are enclosed by black surfaces the white bars in Figure 393 (left) seem whiter than they actually are, and at the points where they intersect with other white bars they look darker. Consequently, the points of intersection look like grey spots. The opposite is the case in Figure 393 (right). No wallpaper or textile manufacturer would put such a pattern on the market. The danger is avoided by using neither pure white nor pure black; instead, the two tones are accommodated by being mixed.

Twilight Contrast. Because of the effect of contrast the sky looks

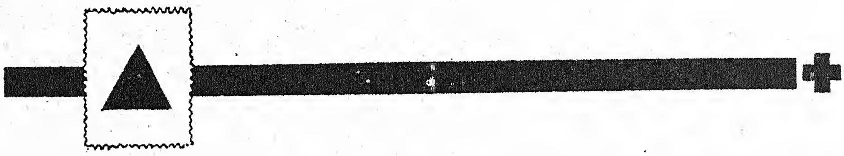


FIG. 395. *Finding the blind spot. Close the right eye, and from a distance of about a foot fix the left eye upon the cross at the right edge of the drawing. When the head is in a certain position, which must be determined by moving it from side to side, the rectangle with the black triangle disappears because it has been projected upon the blind spot, or point of entry of the optic nerve, which is insensitive to light.*

brighter in the twilight, and the shadows of mountains, trees, houses, and telegraph poles appear darker. Contrast accentuates silhouettes, pre-eminently those in the periphery of the visual field, as is indicated in Figure 388 (III). Besides, the periphery of the retina is especially sensitive to motion. These two characteristics of the twilight eye—the increased sensitivity to contrasts and the keener perception of motion—have apparently developed in the course of animal history because they are vitally important in the animal's struggle for existence. During the perilous twilight hours they enable it to recognize hungry nocturnal animals that stalk it from the sides or from behind. In contrast to man, animals with their laterally situated eyes can use the periphery of the retina to look not only sideways but also backwards. A hare, for instance, sees the dog which is chasing it.

The Visualization of the Retina. When light is thrown into the eye through the pupil and the illuminated retina is examined with a magnifying glass, it presents a glowing red appearance. The most prominent feature is the optic disk, a round or oval structure about 1.5 mm. in diameter, which marks the entrance of the optic nerve into the retina [Fig. 394 (a)]. From the disk the bright red retinal vessels radiate like fiery serpents, dividing into innumerable branches as they spread over the retina. Near the disk is the central optic pit, the fovea, which appears as a yellowish spot. It is truly a fascinating picture and is one of the most beautiful of all natural phenomena.

The Optic Disk. In its central part the disk generally dips down to form a physiological depression, which varies considerably in depth and form from one individual to another. It is usually a pale pink, in contrast to the red colour of the rest of the retina.

Diagnosis From the Eye

The retina is a projected part of the brain, and in consequence the optic nerve, like all parts of the brain, is covered by cerebral membranes and surrounded by cerebral fluid. If the fluid pressure within the skull is increased because of inflammation, swelling, or tumour of the brain, the intra-ocular end of the optic nerve, the optic disk, becomes congested and swollen, forming the so-called choked disk. For this reason whenever a brain disease is suspected, an examination of the retina should be made.

Retinal examination is also important in diagnosing many other diseases of the retina, the optic nerve, and the circulatory system, and consequently occupies an important place among the diagnostic methods of medicine.

The Blind Spot. The point of entry of the optic nerve contains no visual cells and is consequently a blind spot, comparable to a scratch

FIG. 396. *We make an important discovery: if the white space between the two black bars is projected upon the blind spot, the white space disappears and we see one continuous black line. Thus the blind spot enables us to see more than is actually present!*

on the photosensitive plate of a camera. In the visual field the blind spot appears as an empty space, which becomes larger the farther one projects it into the outer world.

Finding the Blind Spot

On the retina the blind spot is $\frac{1}{15}$ inch wide; ten inches distant from the eye it is as large as a stamp, at a distance of three feet it is as large as a fist, at four yards it is larger than a human head, and at twenty yards larger than a horse [Fig. 394]. These figures sound improbable, yet one can easily convince oneself of their truth. Very little training is needed to be able to recognize the existence of the blind spot at any time and at any place. Fig. 395 enables us to find the blind spot. Close the right eye and look steadily with the left at the cross, holding the book vertically in front of the face while moving it to and fro. At a distance of ten inches the stamp, the space containing the triangle, disappears. This is the blind spot in the visual field. Having discovered the blind spot and repeated the experiment several times, you are now ready to try several other experiments. First find the blind spot of the other eye. Reverse the book, close the left eye and fix the cross with the right eye, and now try to place the stamp in the blind spot of the right eye. Having

FIG. 397. *Sacred Love. At a distance of about three feet from an object, the blind spot in the eye is insensitive to an area of the visual field as large as a man's fist; this area increases with distance. In order to demonstrate the comparatively large size of this "blind" area, the two figures of a famous painting by Titian, Sacred Love (Above) and Profane Love (Fig. 398) have been placed side by side, providing the subject of an interesting optical experiment, a description of which will be found below Fig. 398.*

succeeded in doing this, return the book to its normal position, and now try to make the cross disappear. After five to ten minutes one is able to make either one or the other figure disappear at will in the blind spot of either eye, and can then go on to the next experiment. Place Figure 395 exactly in front of the centre of the face and look at the stamp on the left with the right eye until the cross disappears; without moving the head, shift the eyes and look at the cross on the right until the stamp vanishes. By alternately opening and closing the eyes one can make either the stamp or the cross disappear without moving the head.

When one has acquired the necessary practice, the book can be laid aside, and one can experiment with various objects. Attach a postage stamp to the wall and make it disappear in the blind spot. Then take a larger surface such as a postcard or a newspaper. Eventually one is able to do the same with almost any object.

Seeing With the Brain

The Psychology of the Blind Spot. The blind spot is not only a physical phenomenon based upon the defective optical mechanism of the eye, but involves also a psychological process. Turn back to Figure 395 again and make the stamp disappear. It vanishes, but

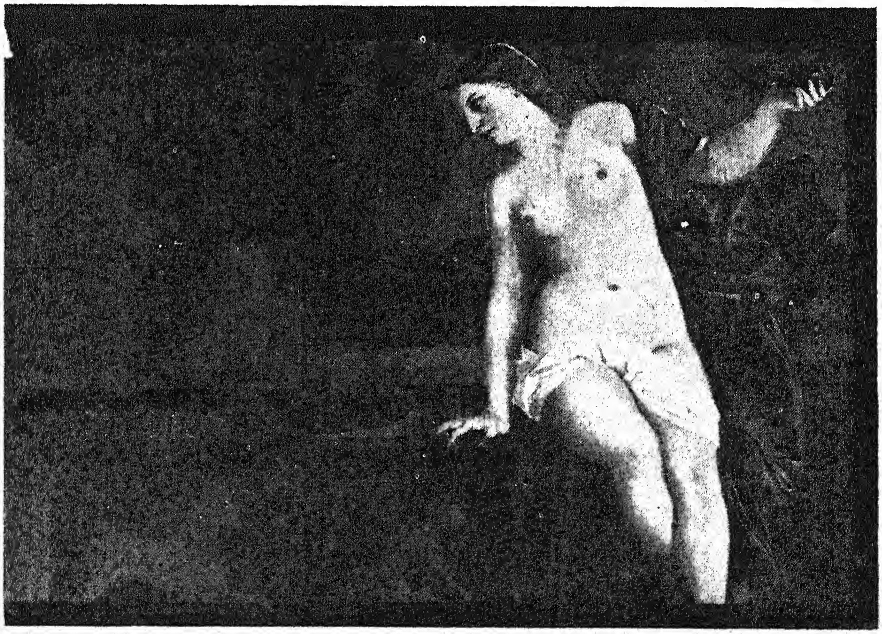


FIG. 398. *Profane Love. Place the book on the table and stand up. Closing the right eye, fix the left eye upon the figure of Sacred Love. If the gaze is now allowed to pass over to the right-hand picture, the figure of Sacred Love disappears in the blind spot when the gaze reaches the figure of Profane Love. If the direction is reversed, the figure of Profane Love vanishes when we gaze upon Sacred Love. The two figures can be made to appear and disappear alternately by opening and closing each eye in turn.*

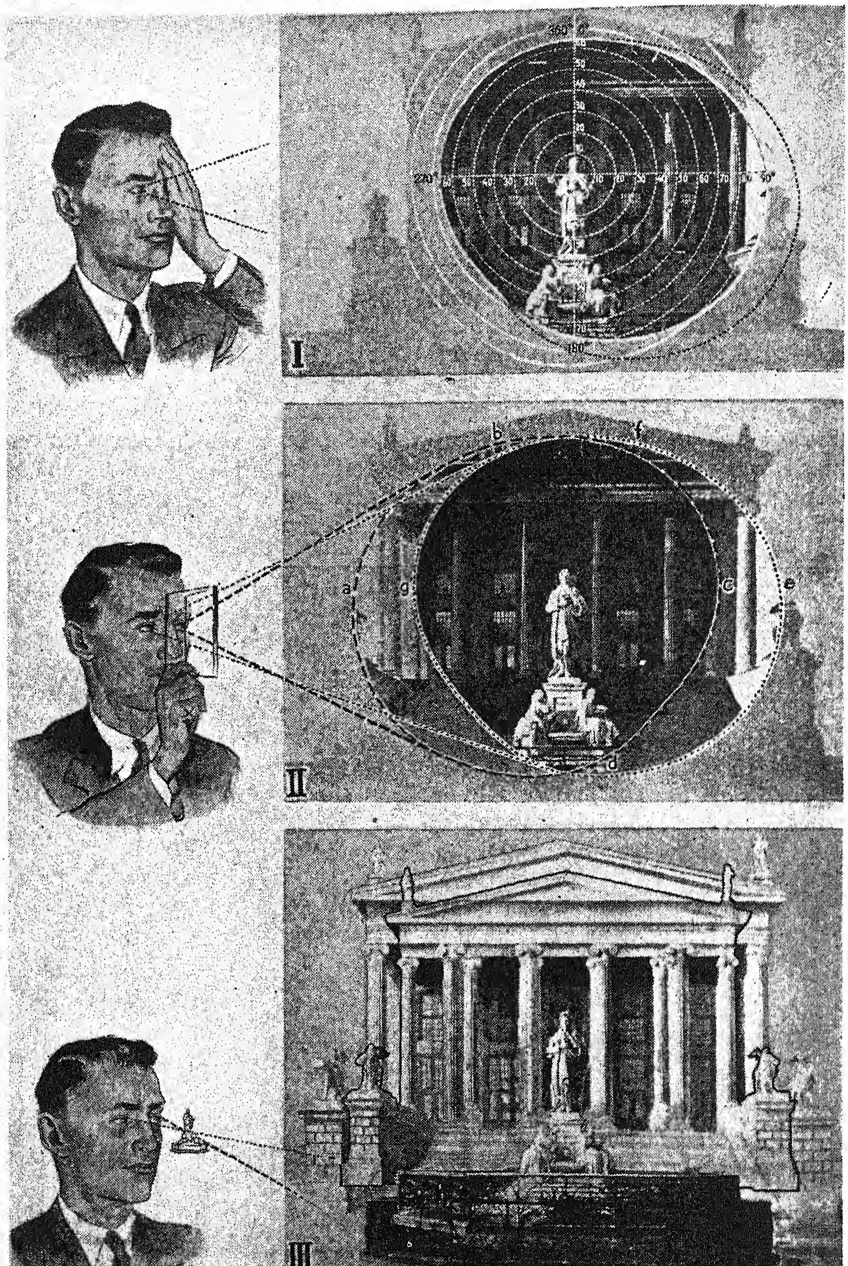


FIG. 399. *At (I) is shown the area surveyed by one eye—in this case, the right eye; in (II) the areas surveyed by both eyes individually have been superimposed. At (III) is the scene as it appears when regarded with both eyes at once.*

the black line exhibits no gap such as certainly exists in the retinal image, and passes without interruption through the visual field. Then experiment with Figure 396. As soon as the white gap is opposite the blind spot, the black line shows no break. Thus the blind spot not only causes no visual defect, but instead allows one to see more than is actually present; that is, one also sees what one would logically expect to be present at this point. If we carry out the directions given in Figs. 397 and 398, so that the figures disappear, we not only close the considerable resulting gap, one-tenth of the page, but also complete it logically. The figure of Sacred Love is placed against a grey background, and we fill in the gap in the visual field with the same light tone; Profane Love is placed against a darker background and consequently the gap is also filled in darkly.

The blind spot is both interesting and important because it demonstrates that while we employ the eye, a physical apparatus which is not entirely free of defects, to see the external world, yet the visual process proper does not take place in the eye but in the brain, where it is controlled by the intellect.

Vision is a physical process in the eye; perception is a psychological process in the cerebral cortex. In practical activity, however, it is even easier to overlook the blind spot, because we see with two eyes, the consequence being that the right eye overlooks the gap in the left visual field, and the left eye that in the right visual field.

The Monocular Visual Field. Figure 399 (I) represents the visual field of a single eye, in this case the right eye. This is known as a monocular visual field. While the visual field is sub-divided like a shooting-target, it is not flat like the latter, but is shaped rather like a hollow sphere. Extend your arms in the direction of the tip of the nose as in a gymnastic exercise; on this "visual axis" the pole of the sphere is located at 0°. Now carry the arms laterally until they are 180° apart,

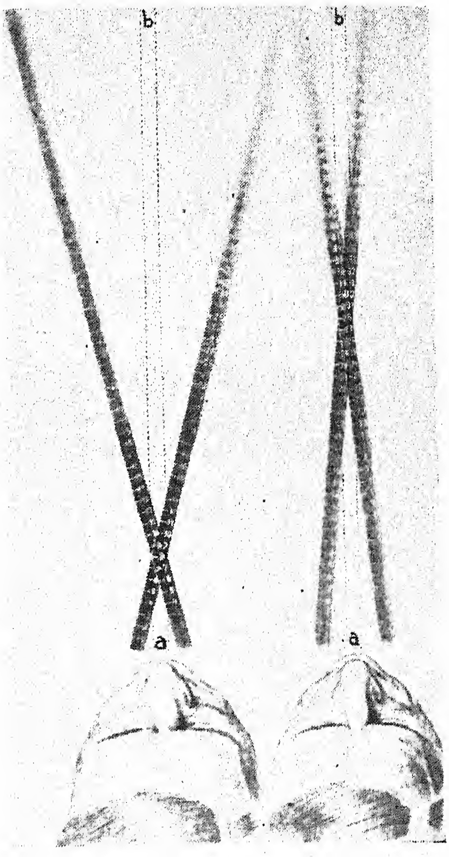


FIG. 400. *An experiment which is as simple as it is astonishing! This is how we see a tape measure stretched between (a) and (b). We do not see it in its actual position, but laterally with each eye, so that it appears double. Only the point at which the two visual axes intersect each other appears single and distinct.*

forming a line which passes through both shoulders; out here the equator of the visual field passes at 90°. Now close the left eye; the spatial area which the eye surveys is the monocular visual field of the right eye. It is shaped like a spherical vault, and is bounded medially by the nose at about 62°, above by the eyebrow at 69°, and below by the cheek-bone at 76°. Laterally, the visual field extends beyond 90°; that is, it extends somewhat posteriorly, up to about 94° in the daytime, and considerably farther in twilight [cf. Fig. 388 (III)].

The Binocular Visual Field. After having understood the monocular visual field of the right eye, close the right eye and examine the visual field of the left eye. In Figure 399 (II) the two visual fields are shown in their natural positions and partially superimposed: (a), (b), (c), (d) indicate the visual field of the left eye, (d), (e), (f), (g) that of the right eye. Since the two are superimposed, the central space is common to both of them, while each of the crescentic edges belongs to only one eye. In order to comprehend this clearly, open and close the right and left eye alternately several times in succession. By doing so, one sees how the nasal ridge, which forms the medial border of the visual field, shifts back and forth. Whatever lies between these two boundaries is seen by both eyes. This egg-shaped area between (b), (c), (d), (g) is called

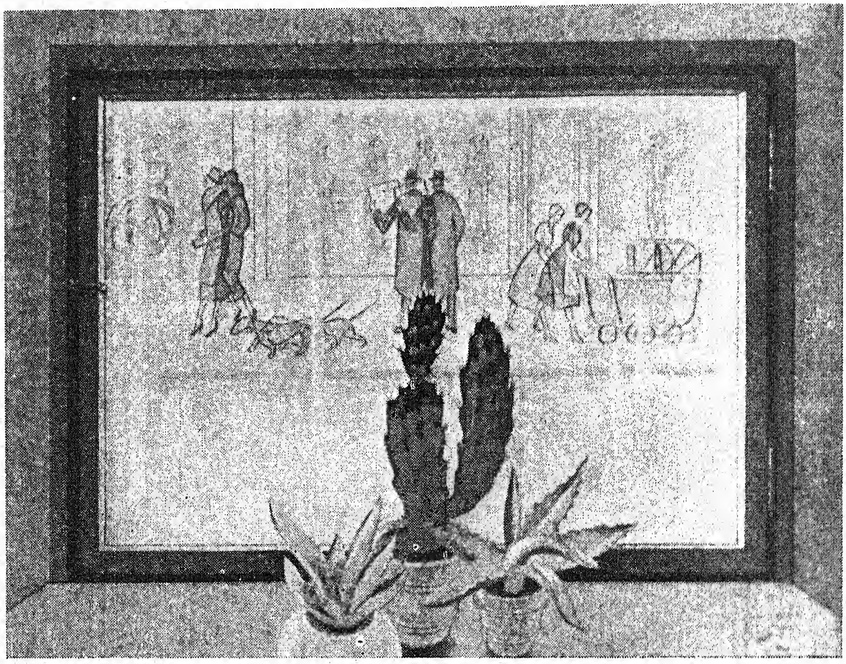


FIG. 401. *This is how we see the world! When we look at an object on our side of the window everything in the distance beyond the window appears to be double. Conversely, when we look at the world outside the window, objects on this side seem double.*

the binocular visual field. On closing the right eye the crescent between (c) and (e) disappears, while closing the left eye results in the disappearance of the left crescent between (a) and (g). These two external crescentic fields are not seen by both eyes together, but by each eye alone. Turn back to Figure 295; the cat stands in the common binocular visual field of both eyes, and, owing to the peculiar crossed structure of the optic tracts, is apprehended not only by both eyes but also by both cerebral hemispheres. But the birds are located in the lateral crescentic area and are seen only monocularly, each image being taken care of by only one hemisphere.

One-Eye and Two-Eye Vision

Whatever stands directly in front of us (between the boundaries formed by the ridge of the nose) is seen by both eyes simultaneously, and perceived in both cerebral hemispheres. It is seen by means of the cones of the central optic pit, the fovea, and is consequently perceived distinctly, in a plastic manner, and in its true colours. Whatever is located outside the binocular visual field, in one of the crescentic visual areas, is observed by only one eye, perceived by one hemisphere, and, moreover, is seen only by means of the rods. It is therefore seen indistinctly and is flat and devoid of colour.

Plastic Vision. Hold an index finger in front of the nose and look at it alternately with each eye. The right eye sees it more from the right, and the left eye more from the left. The right eye (with its external crescent space) sees a border which the left eye does not perceive, and conversely the left eye sees an additional border at the left edge of the visual field. When the finger is looked at with both eyes, it is encompassed by the two crescentic areas, and appears as a solid object. The closer an object is to an observer, the greater is the appearance of solidity which it presents. In combination with psychological experience, the

FIG. 402. *If one looks past the tip of a cigarette the latter shows a double image. The match, being farther away, exhibits two images still farther apart.*

degree of solidity presented by an object permits us to judge distance. Whatever appears solid is considered near, while objects which lack solidity are regarded as distant.

Why Use Prisms? Now one also understands the remarkable form and the incontestable advantage of modern field-glasses. By using prisms the two visual fields are pushed apart. This explains why prismatic field-glasses are wider anteriorly, where the objectives are situated,

than they are posteriorly, where the eyepieces cannot be farther apart than are the eyes themselves. As the visual fields are pushed apart laterally, the observer's gaze encompasses the objects and they appear closer and more solid.

Single and Double Vision. Hold an index finger between your nose and the book and continue reading. The index finger appears double, because the eyes see it from different positions and consequently also in different projections against the page of the book. In order to see the finger singly, the eyes must be rotated inwards—that is, converged—and the two separate images must be fused. Physiologically we see everything double, because we see the world with two eyes, each of which occupies a different position. We see everything double except the point at which the visual axes of both eyes intersect. Take a cord about a yard long, or a tape measure, and attach one end to some object at about eye level. Bring the free end to the tip of the nose, and now look along the extended cord. A very simple experiment, and yet—what a surprise for anyone who performs it for the first time! [Fig. 400].

Double Images

One sees two cords which appear to start from the eyes and to meet at a point of intersection. If the observer lets his gaze pass slowly from the tip of the nose to the attached end of the cord, he will see that the point of intersection of the two cords moves with it. The two cords always intersect at that point which we fix with both eyes. There we see the cord as it actually is: namely, single; at all other points it appears double and at the same time indistinct. In Figures 401 and 402 our experience with the cord is translated into practical actuality. These pictures are not intended to be regarded as jokes; on the contrary, they are true representations of our picture of the world. All other pictures, which are presented to us in paintings, drawings, or magazine photographs are false. They represent the camera's "view" of the world, but not that of a human being with binocular vision.

Defects of the Eye

And now, having traversed the road to knowledge step by step, compare Figure 388 (I), the picture which led to our entire discussion, with Figure 399 (III), the final picture. No one will deny that he has become wiser between these pictures! Not very long ago every one of us would have sworn that he sees the world as it is represented in Figure 388; now, however, we know that the stereoscopic camera that we have in our head is a rather imperfect instrument. We manage so well with it in the world because, first, we know how to employ it in masterly fashion as a result of uninterrupted use; secondly, because we have become accustomed to its defects; and thirdly, because it is equipped with a superbly functioning mechanism which moves and adjusts it. The eye is undoubtedly a primitive optical instrument, but in its muscle apparatus it possesses the best type of adjusting mechanism that is known to technology.

The Muscles that Move the Eyes. Of all muscles in the body, those which move the eyes are outstanding for the accuracy of their responses and the precision of their movements. Each eyeball is supported

and moved by six muscles, four straight and two oblique. The straight muscles are arranged symmetrically: the superior one pulls the eye upwards, the inferior one downwards, the inner one medially, and the outer one laterally. In Figure 373 the external muscle is seen at (f), the inferior muscle above (e). The oblique muscles rotate the eye in the oblique diameters of the visual field. The inward rotators are the strongest, since they are used most frequently, and when a person becomes tired or faints, the eyes rotate medially owing to the predominance of the superior oblique muscles. Next to the muscles of the larynx, the ocular muscles are the most delicate in the body.

When a person is put in front of a large chart, it is found that he can focus his eyes on about 2,000 points along each of the four main

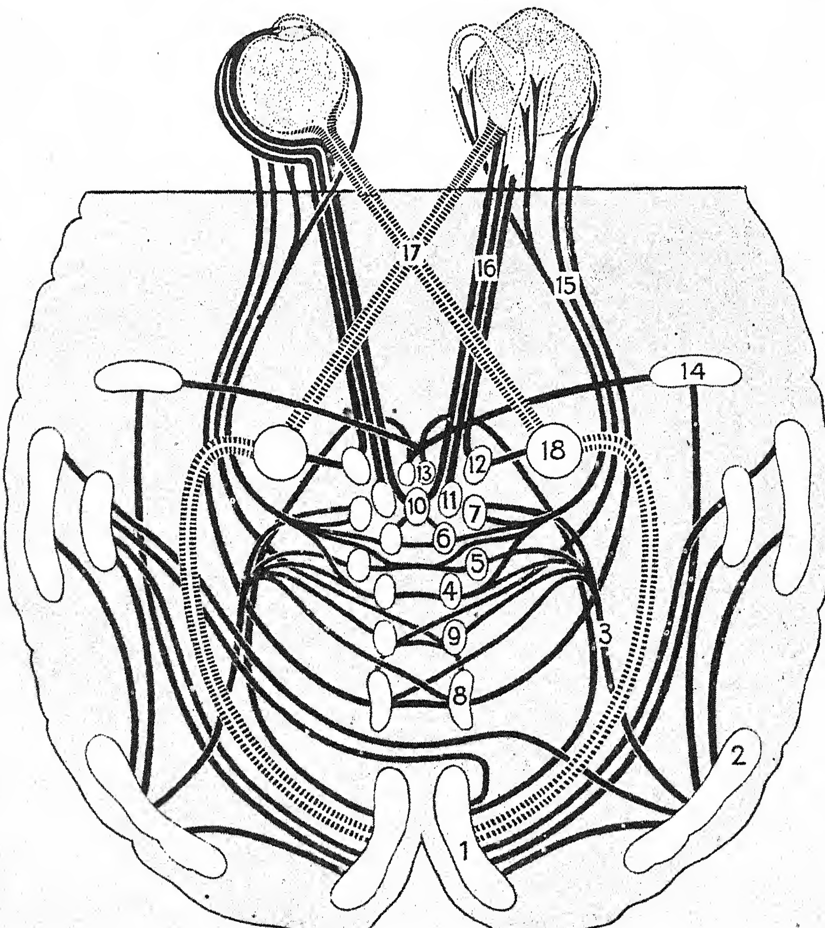


FIG. 403. *One of the most complicated systems of the human brain—the nerve tracts through which the movements of the eyes are directed.*

axes (two horizontal and two vertical) of the visual field (the numbered lines in Figure 399, I). This means that the eye can assume 8,000 positions along these axes alone. The chessboard of the human visual field has more than 100,000 fields among which the observer's gaze can move back and forth!

The Nervous Apparatus for Eye Movements. Figure 403 represents a sketch of the centres and nerve tracts that control the ocular muscles. In order to obtain some idea of this apparatus, let us survey superficially how it works within us at this moment when we are reading. The light stimulus first passes through the optic nerve (17) and the optic tract to the optic thalamus (18), and then to the visual centre (1) in the occipital region of the brain. This centre sees the image and sends it to the various perceptual centres (memory and word-formation), as well as to the volitional centre for voluntary ocular movements (2). From this cortical centre impulses now pass by way of the tract (3) to the various special centres for the eye muscles located in the depths of the brain. The accommodation centre (10) increases the curvature of the lens, so that the lines appear distinct; the convergence centre (11) rolls the eyes inwards, so that the images seen by the two eyes will blend; the pupillary centre (12) regulates the ocular diaphragm, depending on the degree of illumination; centre (13) controls the mechanism which keeps the eyes open; centre (7) fixes the eyes at the right level; centre (8) draws the right eye outwards while reading, while centre (6) pulls the left eye inwards. Upon reaching the end of the line, various inhibitory centres become active, and now the movement is shifted in a complex manner. Since the next line is lower, the centres for the oblique eye muscles must now act for a moment in order to bring the eyes obliquely downwards. In order to prevent the eyes from being carried too far to the left and downwards, other inhibitory centres are brought into play. In short, anyone who wishes to trace the physiological processes involved in

FIG. 404. *The blind space. Between the nose and the point closest to it at which the visual axes cross is a space in which we see nothing—the blind space. In those animals whose eyes are situated laterally, this space is very large. A rabbit, for example, does not see the food which it is eating. On bringing the centre of this picture close to the tip of the nose, the central figure disappears. The two lateral figures approach more closely together, however, as the medial convergence muscles become more and more fatigued, until at last the figures appear to kiss each other.*

reading a page of this book will soon find that he is dealing with a veritable maze of inter-related functions, to which must be added the psychological processes connected with recognition, memory, understanding, and imagination. A full account would probably cover at least twenty pages such as these, and even this might not be enough.

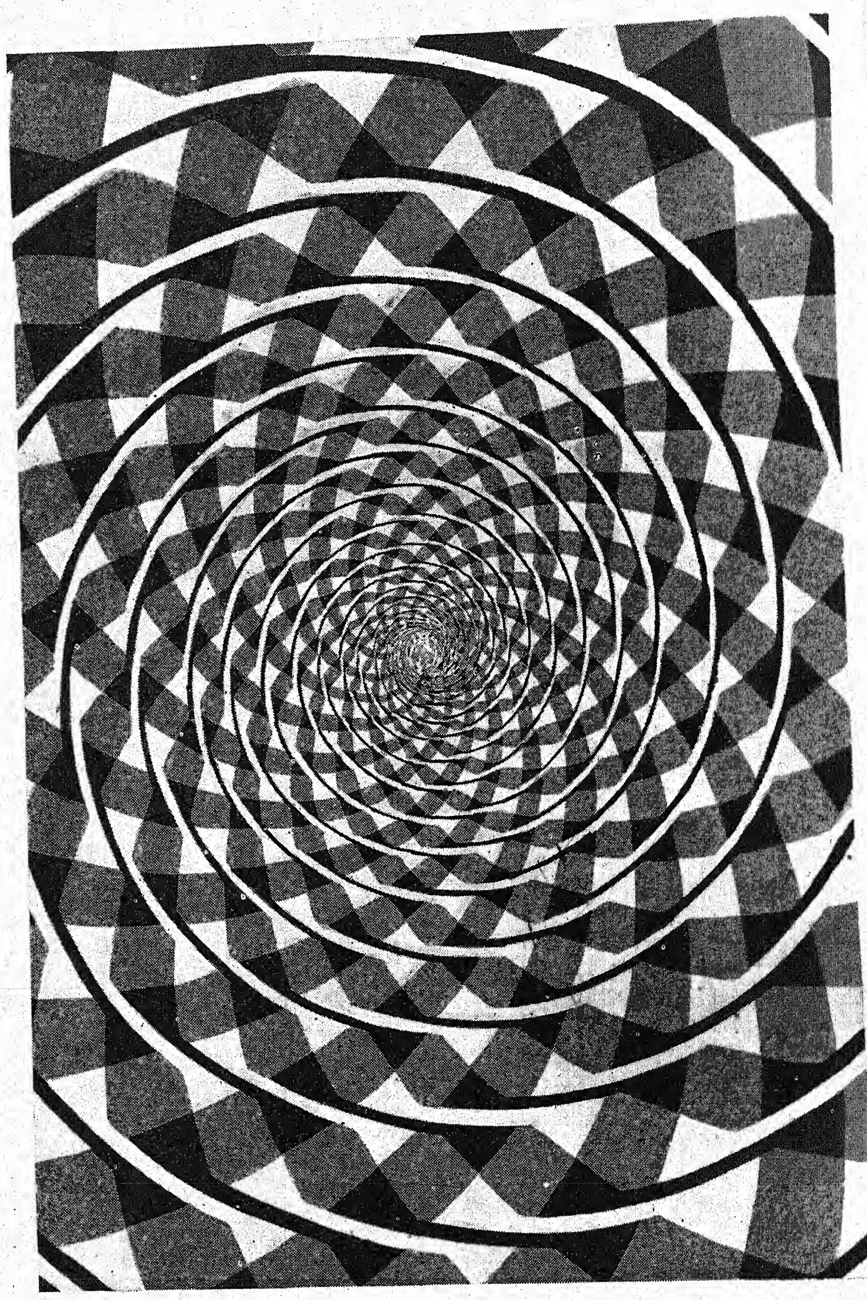
Spatial Orientation and Estimation. How does one estimate the weight of an object? By holding the object in one's hand and judging the degree of muscular effort required to hold it; that is, it is hefted, thus enabling one to estimate the probable weight. In judging distances, angles, and spatial relations we proceed in a similar manner, with the one difference that in the latter case the ocular muscles are employed instead of the arm muscles.

Judging Size and Distance

Let us stop reading for a moment to estimate the size of the room in which we are sitting, and observe what we do in order to arrive at this estimate. With our eyes we traverse the distance from one corner to another, our gaze travels back and forth two or three times, and when we come to the terminal point of the visual axis along which we are looking, the eyes are focused sharply upon it. The distances traversed by our eyes are estimated on the basis of the amount of energy and the time required for the movement of the eyes. This judgment is based not only on the coarser ocular movements, but also on the more delicate movements concerned with inward rotation of the eyeball and the alteration of the curvature of the lens.

Light, Shade and Colour

We judge the distance of an object by the effort needed to accommodate the eye to see it distinctly—that is, by the amount of energy required for the tension of the lenticular muscles, or accommodation, and for the inward rotation, or convergence, of the eyes so that the object will not appear double, but single. Furthermore, we take the apparent solidity of the object into consideration. Everything that is spread out on a plane surface and appears flat, we regard as distant, while objects which the gaze encompasses laterally and which thus appear to occupy depth are judged to be near. The relations of the distribution of light and shade on an object also help in arriving at a conclusion. The stronger the contrast, the closer the object. Similarly, the depth and the length of shadows, as well as the brilliance of colours are also of value in judging relative distances. All in all, the visual process by means of which man orients himself in space is one of very great complexity.



THINGS ARE NOT ALWAYS WHAT THEY SEEM !

FIG. 405. *Are these rings really spirals? No, they are concentric circles. The reader may prove this by tracing the path followed by the apparent spirals. The illusion is due to the slope of the segments, which compels the eyes to look towards the centre.*

CHAPTER XLII

The Psychology of Seeing

HOW EYE MOVEMENTS INFLUENCE VISION. ILLUSIONS OF SIGHT. ESTIMATING THE SIZE OF OBJECTS. OPTICS IN ART AND FASHION. LIGHT CLOTHES OR DARK? THE EFFECT OF ENVIRONMENT. THE POGGENDORF PHENOMENON. CONVERGING AND DIVERGING LINES. PERSPECTIVE. THE WORLD STANDS ON ITS HEAD. THE SPECTRUM. COLOUR TONES. COMPLEMENTARY COLOURS. COLOUR-BLINDNESS.

THE picture of the world that we build for ourselves depends largely on the visual impressions we gather, and here the importance of eye movements must be emphasized. The influence of eye movements is clearly shown in the examples of typical optical illusions which follow. The lines in Figure 406, for example, are actually of equal length. The horizontal line appears shorter to us, however, because it is easier for us to execute horizontal eye movements than vertical ones, in which we must move the eyeballs up and down. This is the physiological reason why the horizon has such a restful effect on us, while mountains tend to produce a restless feeling by compelling us to move the eyes upwards. If one is given the task of drawing a square which is not too small, it is usually drawn somewhat too wide; on the average the width is $\frac{1}{40}$ greater than the height. If one has to draw an upright cross with arms equal in length, the vertical bar is usually drawn $\frac{1}{16}$ too high. Columns appear too narrow because their breadth is seen relatively faster than their height. For this reason, ever since the classical periods of Egyptian and Greek art, they have been made somewhat convex in order to force one's gaze to move laterally.

FIG. 406. *Which of these two lines is longer, the horizontal or the vertical one?*

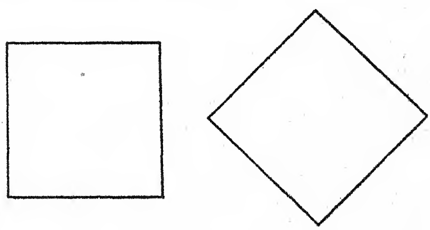


FIG. 407. *Which of these squares is the larger? They are exactly the same size.*

The squares in Figure 407 are of equal dimensions, but the square standing on one corner appears larger, because in order to judge its size we must execute oblique movements of the eyeballs, which require a greater exertion and occur more slowly. Since our eyes move more

FIG. 408. *Which part of this line is longer, the upper or the lower part?*

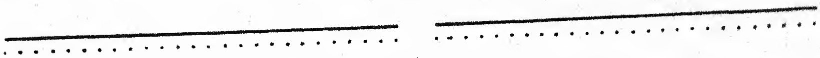


FIG. 409. *Can you divide each of these two lines into halves?*

S 8 S 8

FIG. 410. *Are the figure eight and the S as symmetrical as they seem to be? Turn the page round and see for yourself.*

FIG. 411. *Which of these two horizontal lines is the longer? They are equal in length.*

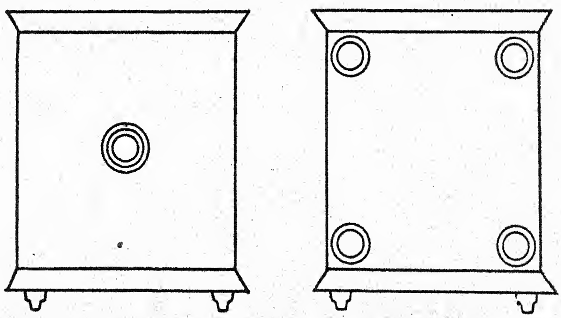


FIG. 412. *Although the door of the left-hand cabinet appears smaller than the door of the one on the right, actually they are equal in size.*

easily along a horizontal axis we are better able to compare and to estimate the size of objects lying alongside each other than of those that are arranged vertically. It is on this account that astronomers in their investigations use instruments which by reflection bring stars that are seen above one another on to a horizontal level; it is a matter of experience that the results of such comparisons are more accurate.

Eye Movements

Everything that lies above the visual axis in Figure 408 is exaggerated, because the visual act is simultaneously combined with the effort of raising the eyes. The two parts of the line are, in fact, equal.

Look at Figure 409, close one eye, first the right and then the left, and see whether you can halve these lines. Test the result by counting the number of dots under each half. In making such a visual division we tend to make the outer halves longer, because we are accustomed to rotate the eyeballs inwards and consequently the muscles that carry out this inward rotation are stronger than those that rotate the eyes outwards (laterally). We can survey the medial aspects of objects much better than the lateral ones.

Figure 410 gives examples of apparent symmetry. The upper halves of the figure eight and the S (left), however, are narrower, but they produce a symmetrical effect, since the lower halves are surveyed more easily by the eyes and consequently appear smaller. Most people are unconscious of any difference; if the characters are turned upside down (right) it becomes obvious.

The lines in Figure 411 are equal in length, but the left one appears shorter because it has an "eye signal" in the centre. The right one seems longer because the vertical line is situated laterally and holds the observer's gaze longer at the end of the line.

The application of the above principle is illustrated in Figure 412. The door of the left cabinet seems smaller than that of the right one because the object in the centre attracts the eye and draws one's attention from the corners to the centre. The objects at the corners direct the eyes outwards. In the realms of art, architecture, and fashion such objects as attract attention play an important rôle.

The line in Figure 413 is divided into two equal parts, but the left half appears much longer because the observer's attention is directed outwards by the attached lines, which diverge, while the right half of the line seems shorter because it is enclosed by lines that converge laterally. One of the numerous instances in which this effect applies may be seen in the lapels of men's jackets. Lapels that point upwards make one appear slim [Fig. 414 (a)]; notched lapels give the wearer a stocky appearance (b).

Illusions in Art and Fashion

The square in the centre of Figure 415 appears higher because the ellipse causes one to look up; the square on the right seems broader because the observer's attention is attracted to the sides.

This effect can frequently be noticed in relation to women's fashions. A hat which extends the profile of the head upwards makes the face seem narrow and long; a hat with a broad brim directs the observer's gaze laterally, making the

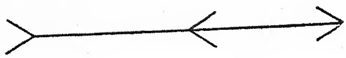


FIG. 413. *Which part of the horizontal line is the longer?*

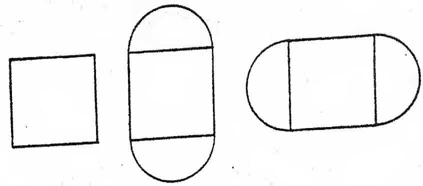


FIG. 415. *These three squares are equal in size!*

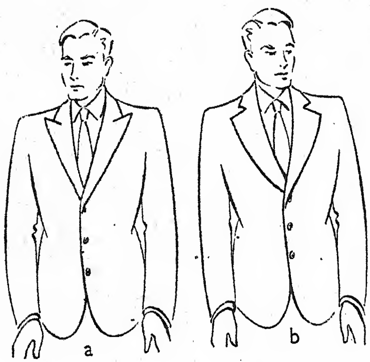


FIG. 414. *The effect of lapels.*

FIG. 416. *Which girl has the broader face?*

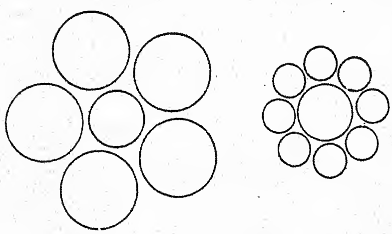


FIG. 417. *The law of optical relativity. Which of the two inside circles is larger?*

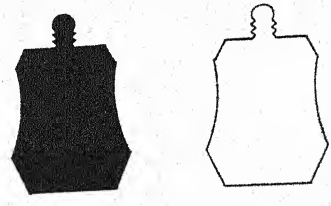


FIG. 419. *An evenly coloured body appears smaller than one of equal size with an emphasized outline.*

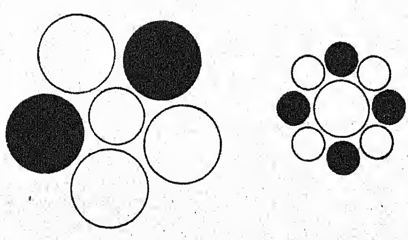


FIG. 418. *The effect of disks and circles.*

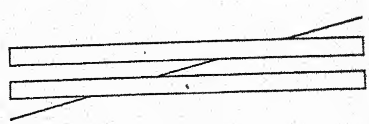


FIG. 420. *The famous Poggendorf phenomenon, named after the mathematician who discovered it. The diagonal line is perfectly straight.*

face seem broader [Fig. 416]. The broader face is a youthful type, so that a wide-brimmed hat gives a woman a more youthful appearance.

The environment exerts an important influence on visual effects. The two inside circles in Figure 417 are of equal size, but the left one seems smaller because it is surrounded and "suppressed" by a number of larger circles, while the right-hand circle appears larger by contrast with the smaller circles that surround it. Diamonds when mounted are surrounded by smaller diamonds in order to make them appear more imposing.

Disks and Circles

A disk appears smaller than a circle [Fig. 418] because the glance passes rapidly across its surface, while circles compel the eyes to follow the much longer periphery, a process which in addition requires very complicated, and consequently slower, movements of the eyes.

A circle appears circular, however, only if the observer's glance can pass around its circumference without encountering any disturbing influence. The two designs in Figure 418 have the same dimensions as those in Figure 417, but do not seem symmetrical because the black disks interrupt the observer's glance. In the design on the right one sees two groups of four dots like those on a domino; the one on the left appears asymmetrical.

The application of a principle is seen in Figure 419. An evenly coloured body appears smaller than one of equal size where the edge is emphasized, since the latter attracts attention and causes the observer to concentrate on it. Dark clothes make one appear slim, while light ones produce an opposite effect. Similarly all patterns that attract an observer's attention for a long time give the wearer a "stout" appearance.

The Poggendorf phenomenon, as it is called [Fig. 420], is the basis of many optical illusions. In this a diagonal line is crossed by two or more parallel bars. As one follows the diagonal upwards, each succeeding piece seems to start farther to the right of the point where the preceding one should end. The explanation

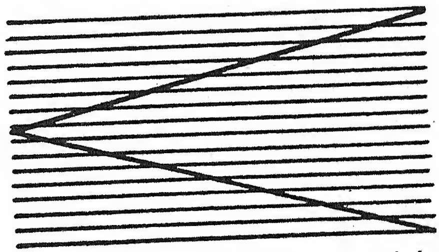


FIG. 421. *Divergent lines crossed by parallel lines appear to be twisted like threads—an extension of the celebrated Poggendorf phenomenon.*

is that in following the diagonal line upwards from the left, our line of vision must cross the parallel bars. The latter deflect our glance even more towards the right, and consequently the next segment of the line appears to the eye to be shifted to the right.

When two divergent lines are crossed by a number of parallel lines, they appear twisted like threads on account of the apparent shifting of the individual segments [Fig. 421].

If you lower your eyes to the level of the book and look at the long diagonal lines in Figure 422, they are seen to be parallel. When we look at them from above, however, our eyes are not capable of seeing

them without being disturbed by the many short lines that intersect them, and are consequently deflected almost automatically. Similarly, it is difficult to see the regular figures in Figure 423 without distortion; while the vertical lines in Figure 424 appear doubly distorted.

The same principle explains the phenomenon in Figure 405. What appear to be spirals are in fact concentric circles. You can believe it without tracing the path followed by these apparent spirals. The illusion is due to the slope of the segments, which automatically compels the eyes to look towards the centre.

Perspective. To see a body in perspective means to see it not only two-dimensionally in one plane, but to perceive it also in its third dimension, in depth. This is an art which the child learns relatively late. Our spatial picture is even less of a direct perception than are our other visual impressions. Space perception is rather a judgment based upon a large number of impressions that have been carefully weighed against one another. It is in a way analogous to the legal proof on the basis of circumstantial evidence. We judge the distance of a house (1) by the relation between its actual size, which we know, and its apparent size as we see it; (2) by the distinctness of its detail — for instance, whether or not we still see the joints between the bricks; (3) by our ability to distinguish angles—for instance, whether (as in the case of a half-open door) we are able to see the angle which we know it must form with the door-post; (4) by the perceptibility of depth. Thus, for example, whether a motor-car standing before a house can still be distinguished from its background, or whether it appears to be attached to the house. . . . It is on the basis of ten or twenty such partial judgments arrived at with lightning speed that our opinion is formed.

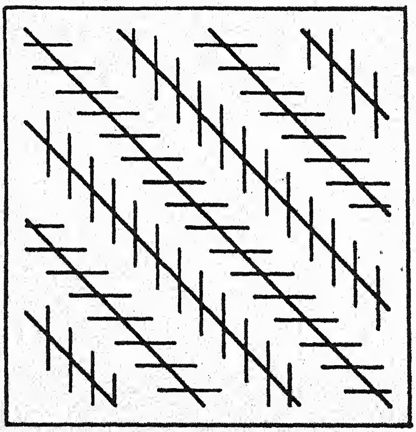


FIG. 422. *These diagonal lines appear to be deflected, but are really parallel.*

More difficult to acquire is the ability to see in perspective something which does not occupy depth, but is spread out on a flat paper or canvas surface. It is entirely comprehensible that the first painters to introduce perspective into their paintings must have been regarded as swindlers by their contemporaries, who attempted to seize the objects apparently located behind the canvas. Yet these primitive attempts at perspective, with their numerous mistakes and inadequacies, appear childish to us now.

To draw an object in perspective means to represent it in such a manner that not all the parts appear to possess equal value. Those parts which are intended to create an impression of proximity should strike the eye and be looked at first; then the gaze should wander automatically from these "nearest" parts to those farther away, and then

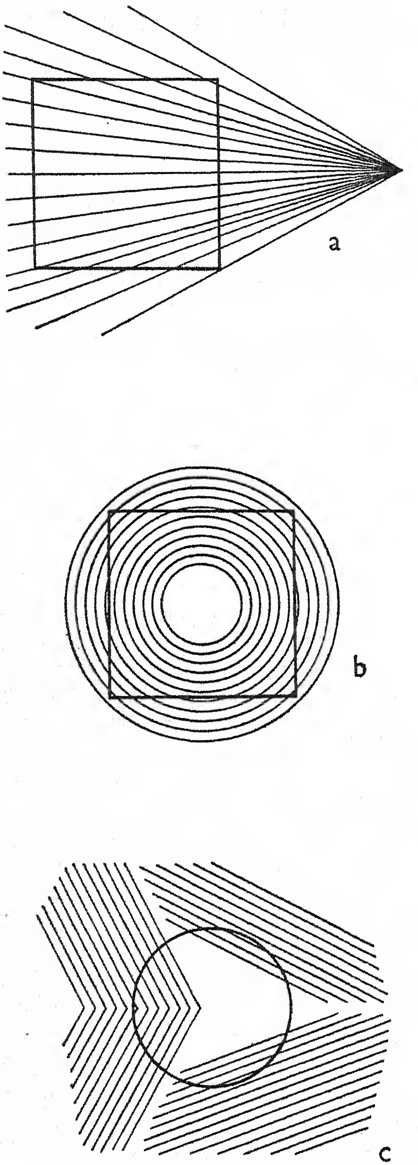


FIG. 423. *The drawings (a) and (b) contain two perfect squares, while (c) contains a perfect circle. These symmetrical figures appear, however, to be distorted, because the intersecting lines in (a) and (c) and the concentric circles in (b) deflect the gaze, making undisturbed vision impossible.*

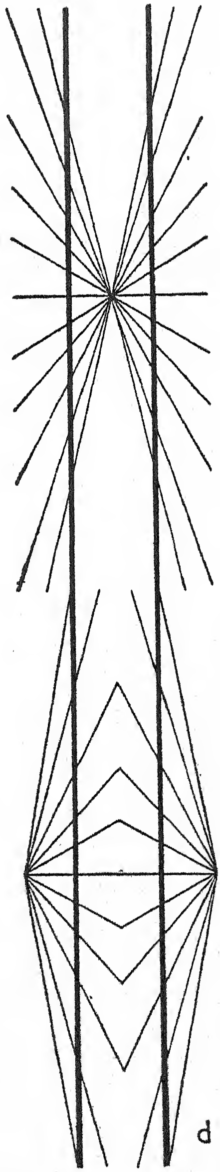


FIG. 424. *The straight vertical lines appear to be bowed outwards towards the top, and inwards towards the bottom, owing to visual disturbance by the intersecting lines. The vertical lines appear to curve in the directions in which the intersecting lines radiate from their centres.*

finally to the farthermost ones. The second rule of perspective is that of foreshortening, the third that of fading colours, the fourth that of foreshortened shadows, etc.

How do you see the "folder" in Figure 425? If one's glance starts at the central fold and moves laterally, the central fold appears to be situated in front, and the folder is seen from outside. If one looks from the edges to the centre, the edges appear to be at the front and one sees into the interior of the folder.

Light and Shade

If one's glance passes from the small square to the large one in Figure 426, the small square appears to be in front, like a lamp shade viewed from the top. On the other hand, if one looks at the large square first and then at the small one, the former seems to stand out in front, creating the impression of an empty room in perspective.

We are acquainted with the fact that light comes from above and consequently judge that light surfaces look upwards, while dark shadowy ones are in the depths. In Figure 427 (A) we see three cubes and in (B) five cubes. If the book is turned upside down, (A) has five cubes and (B) three. However, by turning the book slowly and concentrating on (B), the visual image of five cubes is retained. They appear to be hanging from a ceiling and to be illuminated from below. Yet if the eyes are shut only for a second, this forcibly retained visual image is displaced by the usual one and we again see three cubes instead of five. By occupying oneself for a longer period of time with this drawing so that the appearance of the cubes illuminated from below has become familiar and can be reproduced, one acquires the ability to see at will in each drawing three cubes illuminated from above or five illuminated from below.

We judge that light comes from above and that consequently the picture (A) in Figure 428 represents a cross in relief, while (B) is its negative. Turn the book upside down, however, and the impression changes.

The World Stands on Its Head. The greatest of all sensory illusions has not yet even been mentioned: we see the world upside down as in a camera. If we look at the view through the ground-glass focusing screen of a camera [Fig. 369], the sky is below, the pavement appears above, the motor-cars ride along the ceiling, so to speak, and the shop signs, posters and other advertisements are upside down. This is how the image of the world appears on the retina. We do not read this page from the top downwards, as we think we are doing, but instead from the bottom upwards; we do not read from left to right, but from right to left. The world is upside down. We no longer marvel at this, because we learned about it by experience during the first months of life. During this period we learned that what appears to be right is not really right, but left instead; by grasping a milk bottle we discovered that it was not actually inverted as we saw it, but that the mouth pointed upwards.

An Inverted World

Similarly, we soon learned that people do not walk on the ceiling and that the chandelier does not grow out of the floor. An American scientist put on a pair of glasses which inverted his view of the world. The images which appeared on his

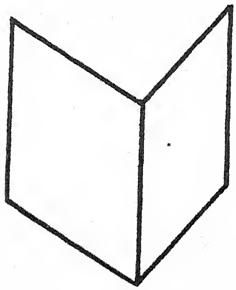


FIG. 425. *This folder appears to present to us its outside or its inside surface, according to whether we regard first the central line of the drawing or the edges.*

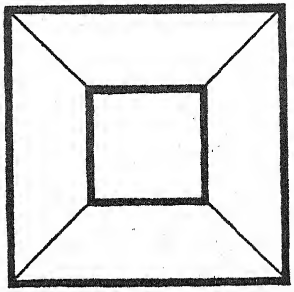


FIG. 426. *If we look at the small square first, it seems to project forward. If the large square is regarded first, the figure appears to be hollow.*

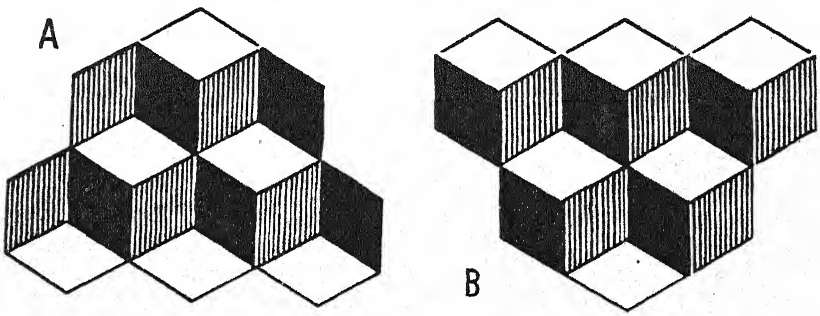


FIG. 427. *The picture (A) appears to contain three cubes and (B) five cubes. On reversing the book, (A) appears to consist of five cubes and (B) of three cubes. On turning the book slowly, however, three cubes are seen in (A) and five in (B).*

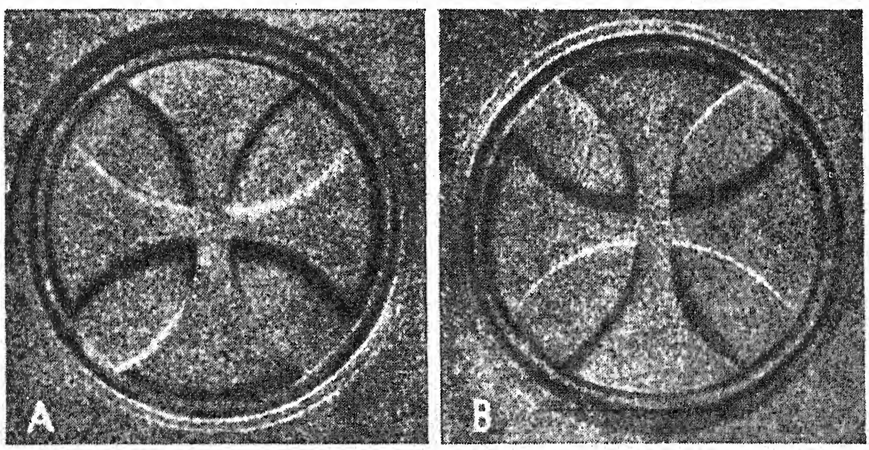


FIG. 428. *We are accustomed to light coming from above, and so the picture (A) appears as a cross carved in relief, and (B) its negative impression. If the book is turned round, however, it will be seen that (B) is merely (A) printed upside-down!*

retina occupied exactly the same position as they did in the external world. But he was not accustomed to viewing the world "correctly"; objects were not in their usual positions, with the result that he was attacked by a kind of "seasickness." He no longer knew how to get through a doorway. People who approached him seemed to be hanging from the ceiling. He was unable to shake hands with them, and in the street he was overcome by a paralysing fear of objects, all of which seemed to him to be coming from wrong directions. Gradually, however, he became accustomed to viewing the world in an inverted manner. After several weeks he was able to move about as confidently as before, and when he took off the glasses, several hours elapsed before he was able to adjust himself to the usual view of the world.

Vision is not a physical process like photography, but rather a psychological experience. It is not the eyes that see, but the brain. The eyes are only physically functioning receptor apparatuses, but the transport of the image to the brain is rather a biological action, and vision itself is a psychological process that takes place in the occipital cerebral cortex, as shown in Figures 295 and 296.

Seeing and Judging

We commonly believe that we see, but actually we form judgments. The decisive factor is not what the lens projects on the retina, but rather what the cells of the cerebral cortex think about this retinal image. The image on the retina bears the same relation to vision as a book to its reader. Just as two people, even when they read the same thing, never have the same thoughts while they are reading, so their gaze may fall upon the same object, but each one may see something different—namely, that which the occipital cortical cells perceive upon the arrival of the optical stimuli, or, expressed more precisely, the sensations which they arouse in the neighbouring areas of the brain [Fig. 430].

Colour Vision

The Spectrum: If one arranges rays of light in the order of their wave-lengths, it is found that the human eye perceives the wave-lengths between 0.38μ and 0.65μ ($\mu = 0.001$ mm.) as light. The rod cells in the periphery of the retina are more photosensitive than the cones in the centre. However, their capacity for discrimination is markedly inferior, since they can distinguish only brightness and darkness. The cones of the central fovea, on the other hand, perceive the individual wave-lengths as colours. Man perceives seven colours in the spectrum: red, orange, yellow, green, blue, indigo, and violet.

Colour Tones. On pouring black coffee into a cup, one sees a dark-brown fluid. If water is added the brown colour does not disappear, but it becomes lighter. Through the constant addition of water the colour of the fluid becomes lighter until eventually the brown tone disappears. The degree of depth of lightness exhibited by a colour is called its shade or tone. Light rays of a certain wave-length produce a certain colour—for example, cause us to have the feeling "red"—and this colour will be produced as long as light of this wave-length acts on our retina. Yet the red may be deepened to the darkest blood-red

FIG. 429. *The greatest of all delusions. The human eye actually sees the world as an inverted mirror image. By means of a psychological correction, which is practised from an early age, we turn the image round, bringing it into correspondence with reality.*

or made weaker until it is an extremely delicate pink. These shades or tones of a particular colour are due to the fact that all colour sensations contain some admixture of black and white. The darker a colour, the closer it is to black; the lighter a colour, the nearer it is to white.

Complementary Colours. If certain pairs of colours are caused to combine in the correct proportion, white light is produced. Thus red and blue-green when mixed correctly form white light; so do yellow and violet. Such pairs are called complementary colours.

The Coloured After-Image. One can easily convince oneself of the existence of complementary colours by the following experiments. If from the colours in a paint-box one takes and mixes a pair of complementary colours, the mixture will not produce any new colours, but instead a dirty grey. If a white sheet of paper is put in front of either Figure 391 or Figure 393, after one has looked at them for a long time, the white areas will appear black because the fatigued eye no longer perceives white. If coloured sheets of paper are used, the after-image will appear green on a red paper, yellow on a blue one, etc. This result is understandable in terms of the colour formula: red + green = white. Accordingly, red − white = green, and blue − white = yellow.

Colour Contrast. If the retina is stimulated by two separate impressions, any differences between the impressions will be accentuated. A red stamp placed on various

coloured surfaces will appear pale red on an orange surface, a deep red on yellow, and on green the colour of the stamp becomes a fiery red. Also two colours of different wave-length appear, under the influence of contrast, to undergo a change in the direction of the complementary colour. If one looks for a consider-

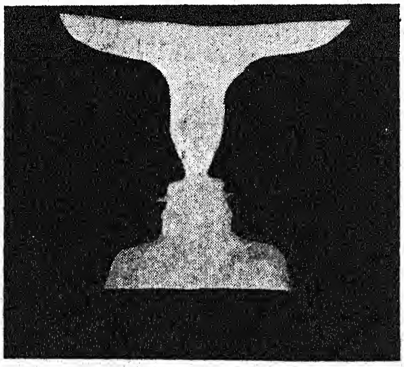


FIG. 430. *Vision is largely a psychological process. If we concentrate on the white surface we see a vase; if we concentrate on the black surface, we see two heads.*

able time at a red stamp on a white paper, the eye becomes fatigued for red, with the result that the paper presents a greenish tinge to the eye (white – red = green). If the red stamp is placed against a black background, the black colour acquires a dirty greenish tinge. For this reason cheap prints, in which the colours are printed carelessly upon one another so that they overlap, appear dirty.

Theories of Colour Vision. All colours can be prepared from the three primary colours red, blue, and yellow, from which are produced the secondary colours violet, green, and orange. The colours of flowers in nature are derived from combinations of pigment granules having the three primary colours, red, blue, and yellow. Films for colour photography work with three elements, and similarly all natural colours may be reproduced by the "three-colour (i.e. yellow-red-blue) process" (+ black = four-colour process). On the basis of these practical experiences it is assumed that the retina also works with three colour elements and contains cones sensitive to red, green, and violet. However, since this hypothesis by no means explains all the phenomena of colour vision, a newer theory assumes that three photo-chemical substances are contained in the retina, each of which is broken down or built up chemically by light stimuli. This theory postulates a white-black substance, a yellow-blue substance, and a red-green substance. According to this theory the sensation of red is the result of breaking down the red-green substance, green the result of its being built up, and similarly for the other substances. But this theory is likewise unable to account for all the problems of colour vision, with which both Newton and Goethe occupied themselves for decades.

The Limits of Colour Vision. Only the cones in the centre of the retina see colours; the rods in the periphery are colour-blind. But not all the cones are equally sensitive to all colours. Studies undertaken to determine the boundaries of visual sensation have shown that the ability to perceive different colours is unequally distributed over the retina. The periphery of the visual field is sensitive only to black, white, and grey. The areas for blue and yellow cover the entire visual field except the periphery, while the fields for red and green sensation are the smallest, being restricted to the central

portion. Evidently, then, the cones in the central part of the visual field are sensitive to all colours, those farther removed from the centre are sensitive to all except red and green, and the peripheral margins which lack cones are insensitive to colour, being able to distinguish only light and darkness.

Colour-Blindness. Colour-blindness may be defined as an abnormality or defect of colour vision whereby certain colours fail to arouse the sensations which they produce in normal eyes.

Figure 431 is a diagrammatic representation of the colour theory. The eye sees red-green-violet (peaks of the curves), and the constituents of these three colours comprise the colours in the spectrum. Among approximately ten per cent of all men—among women less than one per cent—the two curves red-green have been shifted so that they are more or less congruent; that is, rays of red light simultaneously stimulate the elements of the retina that are sensitive to green, while green light acts similarly upon the red elements. Consequently, such an individual sees neither red nor green but only a more or less yellowish grey (in accordance with the formula red + green = white). He is red-green blind. He sees blue, yellow, and violet. Red and green appear as various shades of yellow-grey, and it is on the basis of these shadings that a colour-blind person differentiates them. Of the males with defective colour vision four per cent are completely red-green blind, while six per cent exhibit only a weakness of colour vision. Slight degrees of colour-blindness remain unnoticed not only by his associates but generally even by the affected person himself. A person with defective red-green vision learns at an early age to distinguish between red and green, although he sees both as a greyish yellow. His judgment is not based on colour, but on tone and luminosity. If such a person has not been scientifically tested he can even work undetected as an engine-driver or a pilot, because the green signal lights possess an entirely different luminosity from the red lights, and this enables him to distinguish between them.

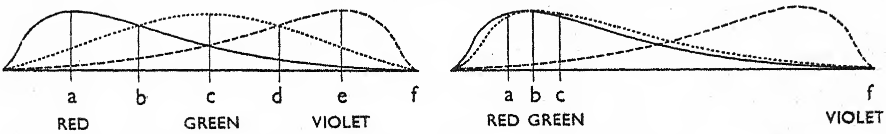
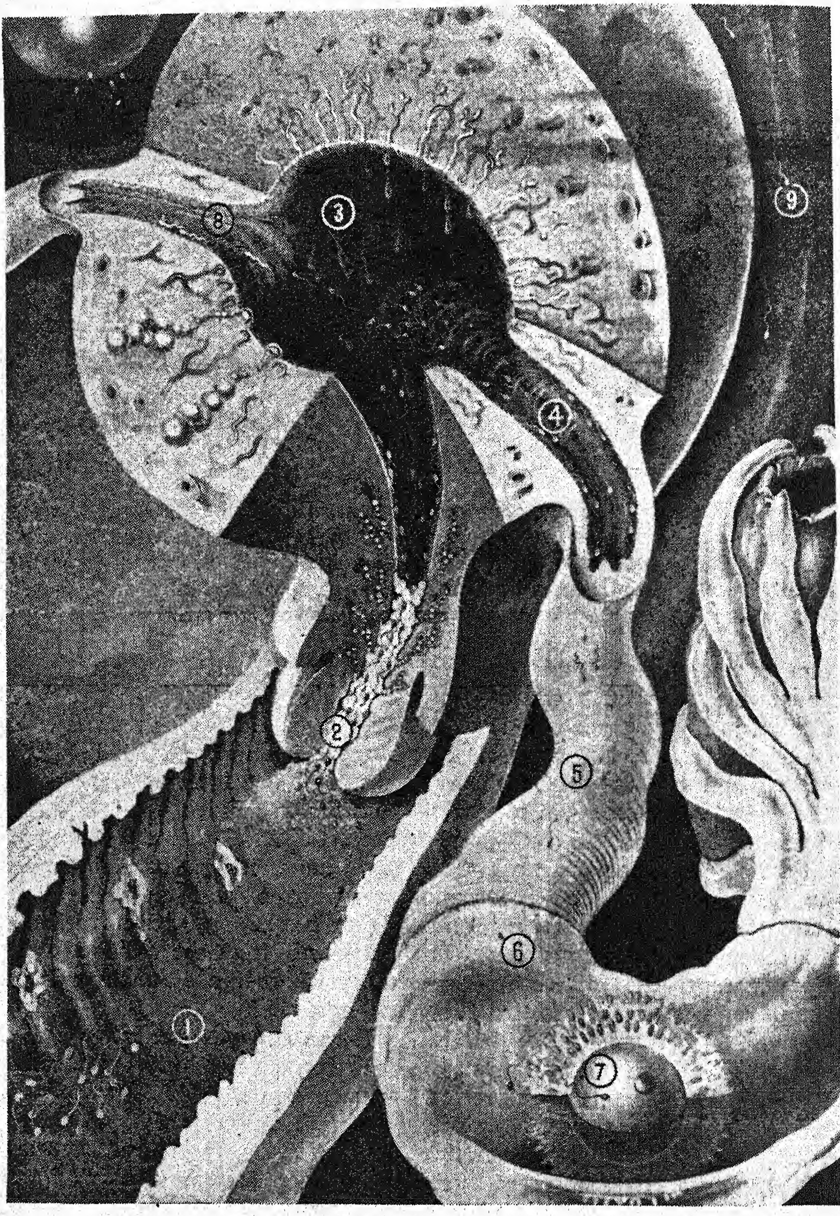


FIG. 431. *The above diagrams illustrate the abnormality known as colour-blindness. In a person possessing normal colour vision (Left) the three colour elements (red, green, violet) are stimulated separately and individually. In a colour-blind person (Right) the green element tends to coincide with the red element, both being stimulated simultaneously, so that neither red nor green is seen, but only red plus green, producing grey.*

It was not until the latter part of the nineteenth century that colour tests were introduced for locomotive drivers. The researches of Holmgren in Sweden in 1877 and of Benjamin Jeffries, of Boston, in 1879, placed such tests upon a sound scientific basis. From that time onwards, standard tests for colour-blindness have been universally imposed upon employees who have to distinguish coloured lights, flags, and signals.



THE MOMENT OF CONCEPTION

FIG. 432. *The male sperms ascend from the vagina (1), through the neck of the womb (2), into the womb (3). Propelled onward by the cilia (4), they traverse one of the oviducts (5, 6) and reach the egg (7). Other sperms enter the opposite, empty oviduct (8) and may escape through it into the abdominal cavity (9).*

X: THE PASSING-ON OF LIFE

CHAPTER XLIII

Reproduction

THE SEX GLAND. THE SEX CELLS. MALE AND FEMALE. THE TESTICLES. SEMINIFEROUS TUBULES. SPERM CELLS. THE EPIDIDYMIS. THE URETHRA. THE PENIS. SEMEN. IMPOTENCE. THE HYMEN. THE VAGINA. THE UTERUS. PREGNANCY. BIRTH. THE OVIDUCTS. THE INFUNDIBULUM. STERILITY. EXTRA-UTERINE PREGNANCY. THE OVARIES. MENSTRUATION AND CONCEPTION.

I. THE MALE

THE life of man begins at the moment when the paternal sperm cell unites with the maternal egg cell to form the egg-sperm cell that will become the child [Fig. 433 (a)]. Through the union of the two chemically different cells an otherwise unknown vital energy is developed. The egg-sperm cell divides rapidly into 2, 4, 8, 16, 32, and finally into thousands of millions of cells, thus giving rise to man. Not all the cells participate in the development of the body, however. Of the first four cells, one is retarded in its growth (b). This quarter of the body which is laid aside during the first hour of human development forms the sex cells (c), and in its totality the sex gland (d). Each of the four primordial cells possesses a certain supply of energy like a charged storage battery. The three body cells use up this energy during youth; with it they build up and develop the body (e). Their growth energy lasts for about twenty years. Then growth ceases. As long as the body cells grow, they inhibit the energy of the sex gland. After this inhibitory influence has been removed, the sex gland begins to produce sex cells (f). Just as the human body consists of two parts, $\frac{3}{4}$ body cells and $\frac{1}{4}$ sex gland, so a human life is composed of two lives: the first comprises the period of youth and is characterized by growth, the second is the period of maturity with the production of sex cells. During youth the body cells multiply while the sex cells rest. At the time of maturity the sex cells multiply and the body cells rest.

The Sex Cells—Bearers of Immortality. Because of the division of the body into body cells and sex cells, man is not a unitary organism, but a kind of double creature, consisting of himself and his sex cells; because of this separation he lives two lives that follow each

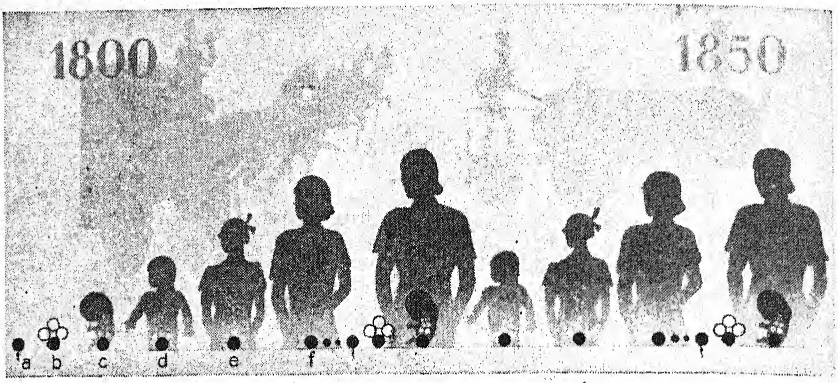


FIG. 433. *A human being springs from the union (a) of a sperm cell with an egg. Of the first four cells (b), three are used for the development of the body, while the fourth remains unchanged as a sex cell. During fœtal life (c) and childhood (d) the body cells grow rapidly, while the sex glands remain comparatively quiescent. With the onset of puberty (e) the sex cells begin to divide and increase, forming semen in boys and giving rise to menstruation in girls. One of the sex cells thus produced becomes fertilized (f), and the cycle of development begins anew.*

other like the voices in a canon. The first life, the life of the body cells, or youth, is lived for ourselves; the second life, the life of the sex cells, or maturity, is lived for the "species," the generations to follow us. The sex cells do not belong to us who bear them, they do not belong to an individual, but rather to the entire species. They are a legacy received from our forefathers which we have to pass on to our descendants. The sex cells are the truly immortal in us, as Plato already sensed when he wrote: "The mortal creature harbours an immortal element: the power of procreation."

The Basic Plan of the Sex Organs. The fundamental plan of the sex apparatus is very simple. The sex apparatus consists of the totality of sex cells, which have been combined to form the sex gland, and a tube of mucous membrane, the sex canal, which transports the mature cells out of the body. The latter structure opens into the region of the anal orifice. Among lower animals these two openings empty into a common "cloaca"; in higher creatures they are separated.

At first the sex glands are situated near the kidneys in the middle of the body, so that the sex canal runs downwards in a straight line (6 o'clock position) [Fig. 435 (a)]. In the course of embryonic development they wander downwards. If the embryo is a female they stop midway in their wandering, and the sex canal forms a right angle (6.15 position) (b). If the embryo is a male, they continue to travel downwards until they are suspended at the inferior end of the trunk diametrically opposite the position from which they started (6.30 position) (c).

The Male and the Female Sex Apparatus Are Congruent. The basic plan of the male and the female sex apparatus is the same, and this correspondence is retained even after full sexual development. To express it mathematically, they are equal

quantities with inverted signs. The male sex apparatus is the positive mould and the female apparatus the negative of the same basic pattern. They correspond like lock and key, or a plastic figure and the matrix in which the figure is moulded [Fig. 436 (Top)]. The sex glands are similar in shape and size. They are called testicles in man and ovaries in woman (a). The male sex cells are called sperms; those of the female, eggs. Two ducts (b), which originate near the sex glands, transport the cells to the outside, and are known as the seminal ducts in the male, as the oviducts (tubes) in the female. They meet in the mid-line of the body, forming a hollow organ. This organ is called the prostate in man and the uterus (womb) in woman (c). In the woman the excretory duct for the sex cells (d) remains within the body, while in the man it protrudes outside the body. In the woman, whose function it is to receive the male organ, the duct becomes wide and the walls thin, so that this part is called the vagina, or sheath. In the man the duct remains narrow and the walls become thick, thus producing the penis.

The External Genitals. That part of the sex apparatus which can be seen externally is called the external genitals. Despite the fact that they appear so different, the external genitals are not fundamentally different. They are but two greatly differentiated terminal forms of one and the same basic pattern [Fig. 436 (Bottom)]. During early pregnancy one cannot tell outwardly, even when genitals have already appeared, whether a human fœtus will become a boy or a girl. In both cases one observes the same basic form (a): above, a tubercle, beneath it a cleft, and two swellings laterally. The male genitals develop by the tubercle becoming large and thick, forming the penis (b), and the cleft closing almost completely, leaving only the tiny opening for the urethra. Later the testicles wander into the lateral folds and in doing so stretch them, producing the scrotum. In a girl (c), the tubercle remains small and becomes the clitoris, the cleft remains open, forming the

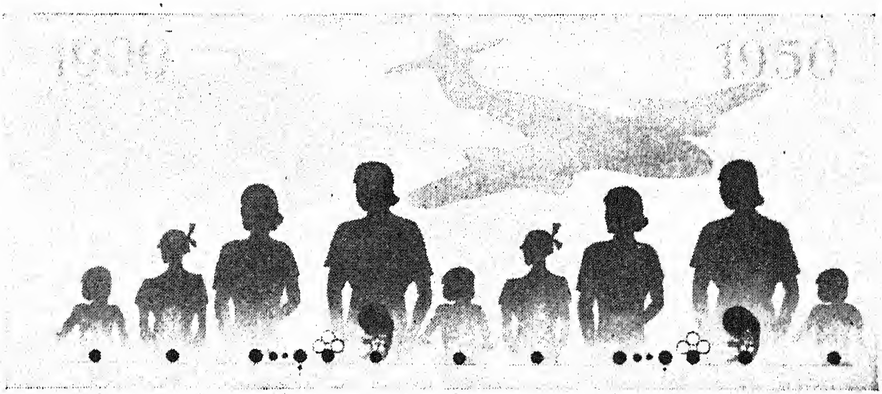


FIG. 434. *The cells that form the human body are transient and die eventually. The sex cells, however, live beyond the life of the individual, bearing the immortal hereditary element which passes from one generation to another as the persistent element of life.*

vagina, and the folds become the labia.

The Testicles. During the last weeks of embryonic development the male sex glands leave the abdominal cavity through the inguinal rings and are suspended in a skin sac, the scrotum. The testicles are the only visceral organs that leave the abdominal cavity and exist outside it throughout life. Despite a great deal of discussion no satisfactory explanation has yet been found for this very remarkable fact. Owing to the wandering of the testicles the seminal ducts are elongated and describe the remarkable curve which can be traced in Figure 438 (1, 2, 3 and 4).

Masterpiece of Packing

The Seminiferous Tubules. Each testicle contains about a thousand seminiferous tubules; the initial portion of each tubule is closed, forming a blind end [Fig. 439 (1)]. Take a spool of yarn and tear off a thread about one yard in length; now you have a model of a seminiferous tubule, since each one of the seminiferous tubules of a testicle is as long and as thick as this thread. The accommodation of one thousand threads, each a yard long, within the small space of a testicle is a true masterpiece of packing technique, and it is indeed worth while to obtain a testicle of an animal from a slaughterhouse and to study it. The tubules are rolled together spirally like yarn on a spool; a thousand small spools are packed together in a gland as large as a plum. The total length of the seminiferous tubules in both human testicles is a mile and a quarter. If one cuts a section of such a thread, about $\frac{1}{500}$ inch thick, and places it under a microscope, a picture such as that at the top of Figure 437 is revealed. About two million sections could be cut from both human testicles, and if each were to be represented as large as this illustration, three thousand volumes as thick as this book would have to be printed with one picture on every page!

Growth of a Sperm

The Sperm Cells. In Figure 437 one can trace the development of the sperm cell from its first appearance to maturity. Above, one sees the aforementioned cross-section through a seminiferous tubule. At the right, next to it, the six stages, numbered (1) to (6), in the development of a single cell can be traced. A thread begins to grow out of the spherical mother cell (1) from its motor centre, the centriole (2). At the same time the cell becomes elongated, and the nucleus moves from the middle of the cell to its anterior pole (3). Both the thread and the cell stretch farther (4), until finally the thread has used up the entire protoplasm of the cell for its growth (5), so that the completed sperm thread consists only of the former cell nucleus and a long tail with a complex structure, which transports the sperm to its destination by means of wriggling movements (6).

Nutritive Cells

In the upper picture these six developmental stages may be found along the radii of the corresponding numbers. However, one must look for them, because the sperm cells are pushed into the centre of the canal by the proliferating masses of cells during the process of maturation. Thus each further stage is somewhat more centrally located

than the previous one. After the cells have used up their protoplasm for the construction of the tail, they stick their heads into the substance of the nutritive mother cells, which are seen to the right and left of number (4), just like an infant at its mother's breasts. The mature sperm cells lie in the central space of the tubule.

The Epididymis. As a result of the constant production of cells the mature sperm cells are slowly pushed forward through the seminiferous tubule and finally out of the testicle into the epididymis [Figs. 438 and 439 (2)]. The epididymis is a reservoir for sperm cells, and is also a masterpiece of packing technique. Here a tube five yards long is folded until it is only two inches in length. For a sperm cell, which is one of the smallest cells in the body, five yards is a tremendous distance—as far as 120 miles for a man. The sperm cell is pushed forward along this entire distance, because in this as well as in the next section it is still immobile.

Male Secretions

The Seminal Vesicles and the Prostate. From the epididymis the sperms are pushed into a tube, called the seminal duct (3), which conducts them up into the abdominal cavity. Having reached the abdominal cavity, the two seminal ducts unite at the base of the bladder and enter the urethra (4). Up to this point the spermatic mass, or semen, is a dry crumbly substance, somewhat like the powder used to make puddings. Now it comes into contact with the fluids of the seminal vesicle (a) and the prostate (4). The

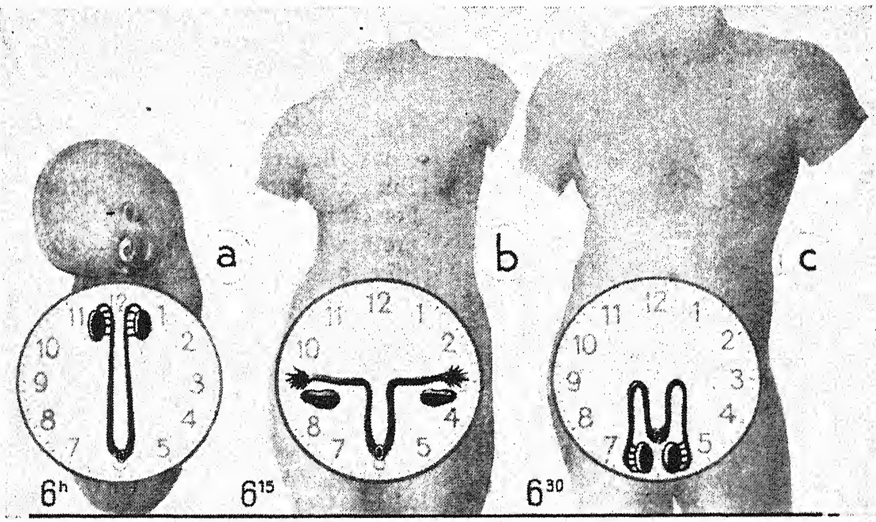


FIG. 435. *The descent of the sex glands. In the embryo (a) the sex glands are at first situated at the point of origin, perpendicularly over the orifice of the sex canals (6 o'clock position). In the body of the developing female embryo they pass downwards and sideways until eventually (b) they are in a horizontal plane (6.15 position). In the male (c) they continue to travel downwards, until they emerge from the body by way of the inguinal rings, being suspended below the original sex opening (6.30 position).*

seminal vesicles produce a viscid, yellowish fluid, containing gelatinous globules resembling swollen sago granules. The product of the prostate is a milky secretion, containing a substance called spermin, which has a fish-like odour. The pike-like odour of ejaculated seminal fluid is due to its spermin content. The mixture of the prostatic secretion with the gelatinous mass from the seminal vesicles gives rise to the seminal fluid, in which the crumbly cell mass is dispersed like a pudding powder in the gelatinous solution, and now the sperm cells become motile.

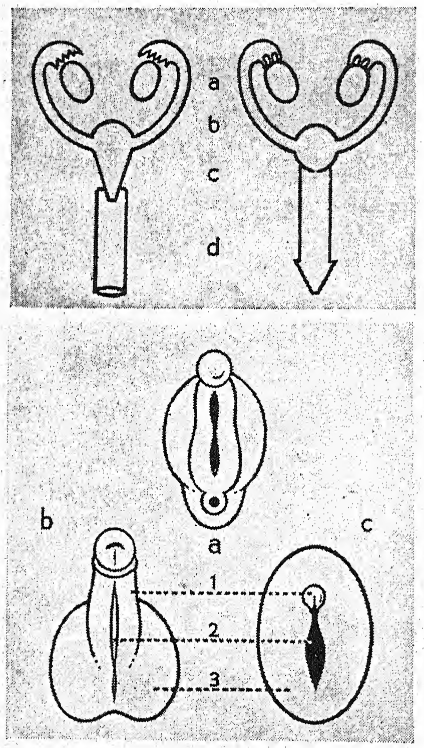


FIG .436. *(Top) The male and female sex organs correspond in their basic structure as well as in the basic form of the external genitals. (Below) Thus the indeterminate genitals of the embryo (a) may develop into those of a male infant (b) or of a female infant (c). The female sex organs are the negative mould of the positive male organs.*

The prostate (4) contains not only glands but also numerous muscle fibres, which surround the beginning of the urethra, so that it is not squeezed or torn by the filling of the bladder or the swelling of the penis. At the same time the muscle fibres act as a valve mechanism which shuts off the urinary bladder so that the seminal fluid will not come into contact with the urine, since the acid of the urine damages the sperm cells. During sexual excitement, the muscle fibres of the prostate contract, closing off the urinary bladder. Not until sexual excitement has subsided does the muscle relax, and the bladder can then be emptied.

Mucous Glands

The Urethra. The urethra (5) is a long, delicate tube which passes ingeniously through the penis the length of its long axis. Since the penis stretches during sexual excitement, the urethra must also be capable of extension and distension. For this reason the wall of the urethra is not smooth like a rubber tube, but folded like the bellows of a camera [Fig. 440 (e)]. In cross-section the folds form a star-shaped figure [Fig. 439 (5)], while along the longitudinal axis the folds lie one behind another like the folds of an accordion. The wall of the urethra contains many mucous glands, of which two particularly large ones, Cowper's glands, lie directly in front of the prostate [Fig. 438 (b)]. During sexual excitement these glands secrete an alkaline glairy mucus, which neutralizes the traces of urine remaining in the urethral folds, thus

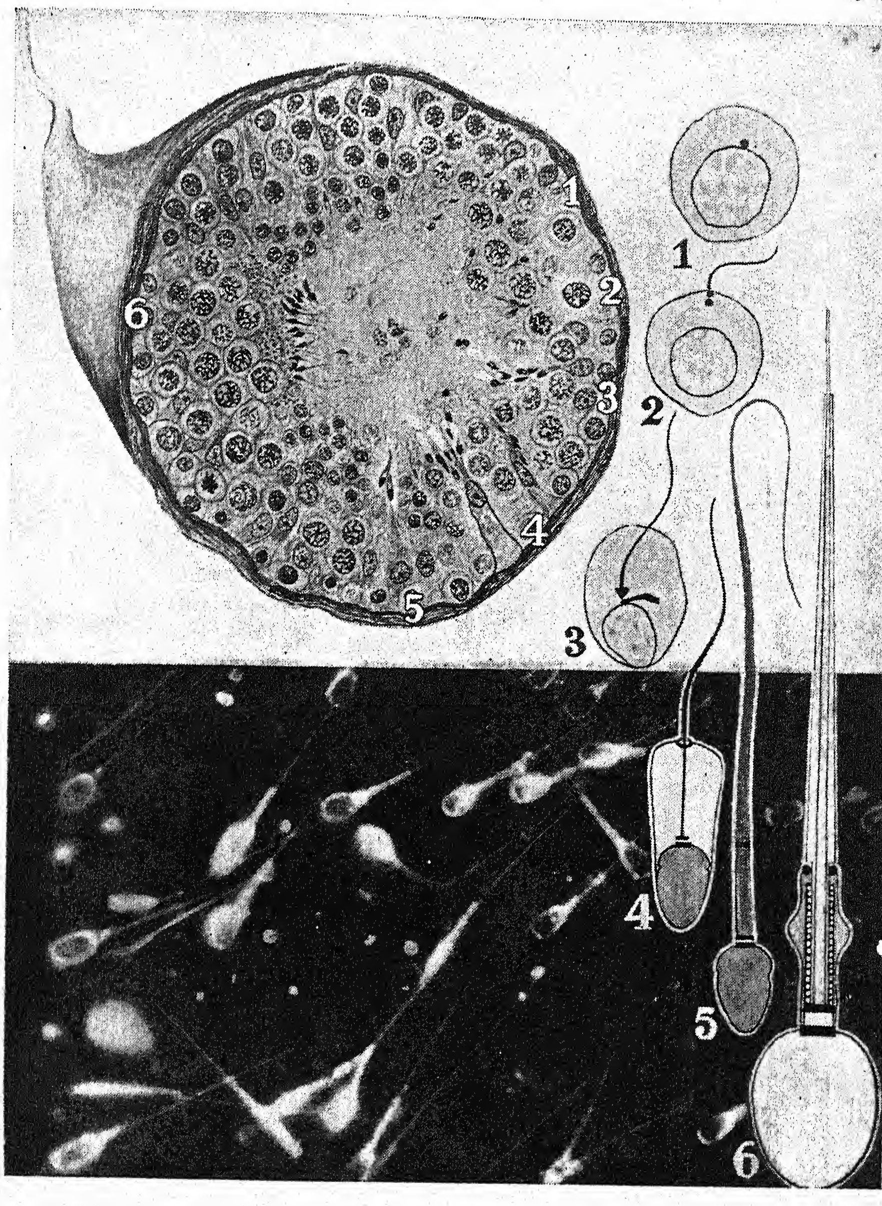


FIG. 437. *Sperm cell production. Above is one of the thousand sperm canals of the testis, seen in cross-section. At the right, from (1) to (6), are the stages of sperm cell maturation. Sperms in each of these stages are to be found among the cells in the cross-section, along the radius adjoining the corresponding number. Apart from a few special forms, the sperms of different animals are so similar as to be almost indistinguishable. Below is a reproduction, from a micro-film, of sperm cells, enormously enlarged. Although similar to those of man, they are the sperms of a sea-urchin!*

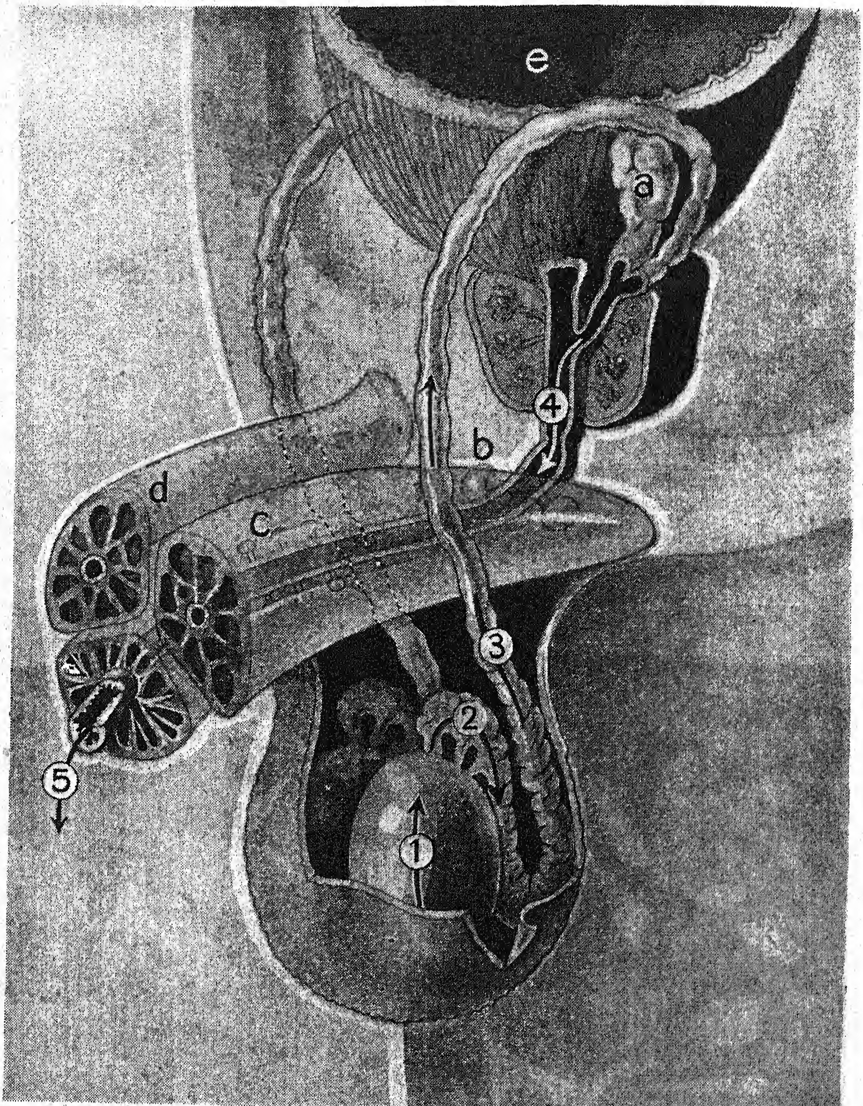


FIG. 438. *The design and arrangement of the male sex organs. Main structures (1-5): (1) the testicle, containing about a thousand seminiferous tubules in which the sperm cells are produced; (2) the epididymis, in which mature sperms are stored; (3) the spermatic cord, through which the sperms travel into the abdomen; (4) the prostate gland, which produces the prostatic secretion and also acts as a "muff" for the urethra; (5) the urethra, which passes through the centre of the penis. Accessory structures (a-d): (a) seminal vesicles, which contribute to the semen a secretion of unknown function; (b) Cowper's glands; (c) mucous glands of the urethra; (d) corpora cavernosa of the penis. At (e) is the urinary bladder, which is not a part of the sexual system.*

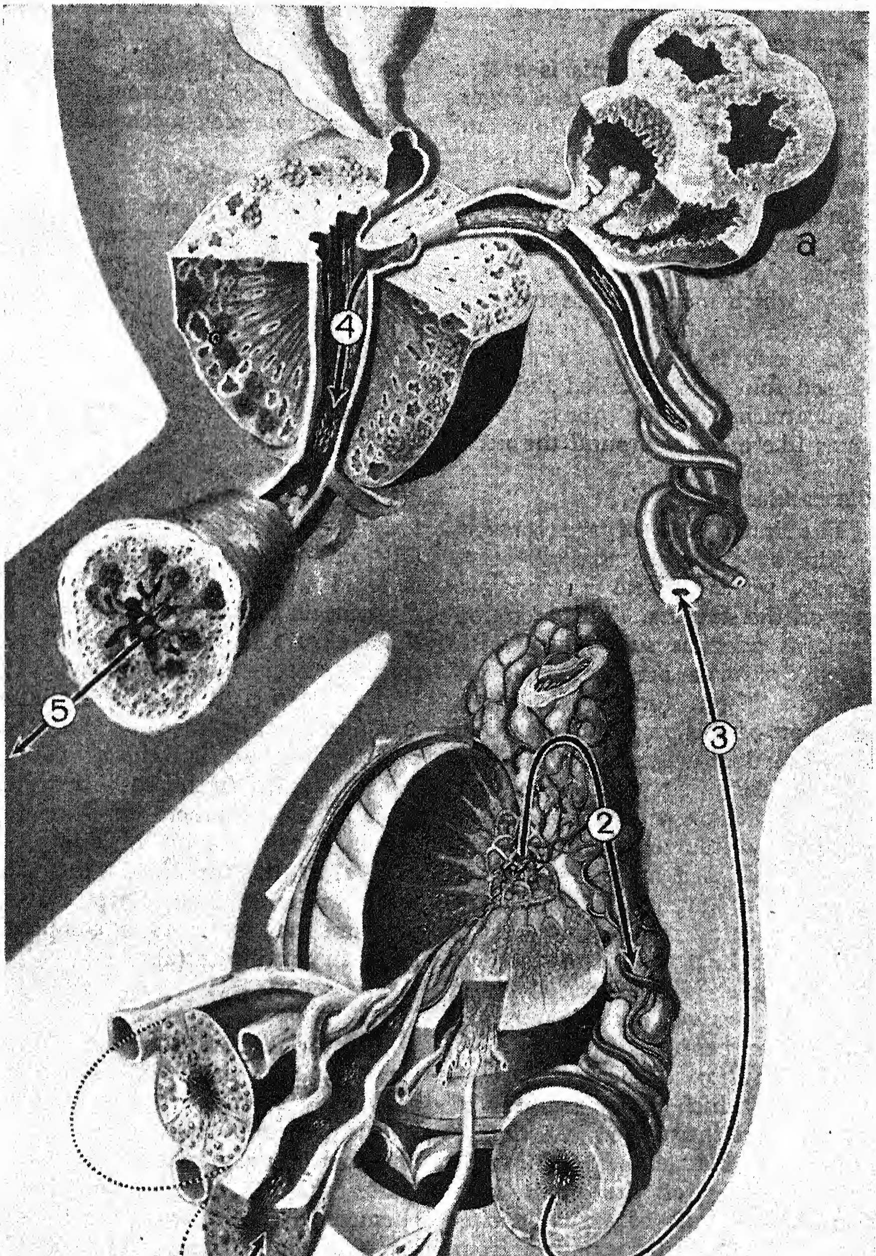


FIG. 439. *Enlarged section showing the structural details of the male sex organs.*

creating an acid-free path for the sperm cells.

The Penis. The penis is a skin cylinder, about as long as a finger. When at rest it is pendulous and flaccid. The urethra passes through the penis along its long axis and terminates at the mushroom-shaped tip. Because of its appearance, the tip of the penis is known as the glans, which means the acorn; it is separated from the shaft by a groove. The glans is covered by a ring-shaped fold of skin called the foreskin, attached to the groove of the glans like a collar around the neck.

Circumcision

The inner side of the foreskin facing the penis contains sebaceous glands, which secrete a sebaceous matter, the smegma. This secretion contains odorous substances which among animals act as sexual excitants. Musk, for instance, is a secretion of the preputial glands of the musk deer when in heat. Many nations, comprising a total of two hundred million people, remove the foreskin by circumcision. For various reasons this is a hygienic measure; in its origin, however, it is not based upon hygienic considerations, but is believed to be a relic of the ancient practice of child sacrifice, which at one time was widespread among a great many peoples.

would not suffice for the erection of the penis, so that this change in size, tension, and position is carried out by means of an extremely interesting and complex mechanism.

Mechanism of Erection

The interior of the penis, the space between the urethra in the central axis and the cutaneous wall of the penis, is filled with three cigar-shaped chambers, called the corpora cavernosa, which can be compared with the gas chambers of a dirigible. They can be seen in Figure 438 between (c), (d), and (5). In Figure 440 (I), one sees the inferior corpus cavernosum together with the urethra (e) in a state of rest, and in (II) during erection, when the organ is filled with blood. The corpus cavernosum consists of connective-tissue chambers, the walls of which contain numerous blood vessels. When at rest (I) they are contracted and permit only traces of blood to pass through, so that the chambers remain empty. In this condition the walls of the chambers lie close together like the folds of a closed camera, so that the blood vessels in these walls describe sharp curves that are very close to a complete break in continuity (a).

"Cork" Cells

Secondly, the walls of the vessels contain thick cells that act like corks (b). Thirdly, when at rest the vessels are contracted by the tonus impulses of the nervous system (c). Under the influence of sexual excitement the contracted vessels relax, the "cork" cells become smaller, and the blood flows without hindrance into the vessels (1) and then through (2) into the chambers of the corpora cavernosa. Owing to

the expansion of the chambers the connective-tissue "guy ropes" of the urethra are tautened in all directions, so that the urethra (e) itself likewise expands without being compressed by the pressure of the blood. In order to obtain a state of increased pressure within the penis the apart so that, unlike the thin overflow veins of the periphery, they open during an erection and permit the blood to leave (3). To prevent too much blood from flowing out, they contain funnels through which the blood flows in a thin stream during the erection. As sexual excite-

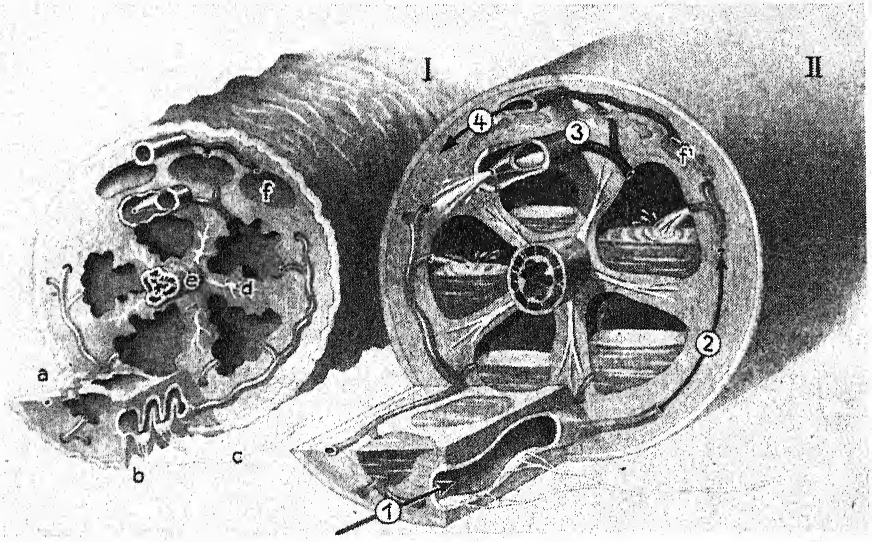


Fig. 440. *The erection. At (I) is a cross-section of the penis when in a state of quiescence, its blood vessels only partially filled with blood. It is soft, flaccid, and wrinkled externally. During erection (II), the vessels fill rapidly with blood, as a consequence of nervous stimulation, thereby distending and stiffening the organ in readiness for intercourse.*

outflow veins are closed during an erection. These veins originate in especially thin-walled peripheral chambers (f), which are open when the organ is at rest, and supply the tissues with nutriment. During erection, however, they are compressed by the pressure of the blood (f^1). To obviate the risk of excessive swelling of the penis which might cause pain, special "overflow" veins are present (3). They are situated in the central walls, which are not compressed by the pressure of the blood, but on the contrary are pulled

ment subsides, the vessels (1) begin to contract again, the blood leaves the penis slowly through the funnel veins (3) and, finally, when the pressure against the peripheral veins (f^1) has relaxed, flows rapidly through the large dorsal vein (4).

The Ejaculation of the Semen. The semen is evacuated by a series of spasmodic contractions of the genital tube. The filling of the testicle with semen creates a feeling of tension; the expulsion of the sperms relaxes this tension. The whole process induces strong pleasure sensations. This

is nature's device to bring about a continual propagation of the species. Upon examining a drop of expelled semen under the microscope, swarms of swimming sperm cells are seen, 225 million "primordial human beings" wriggling about like eels. Each of these cells is laden with thousands of genes, the hereditary elements of the species, and each one is qualified to become a human being by uniting with the egg cell of a woman, as shown in Figure 441, which shows the act of fertilization.

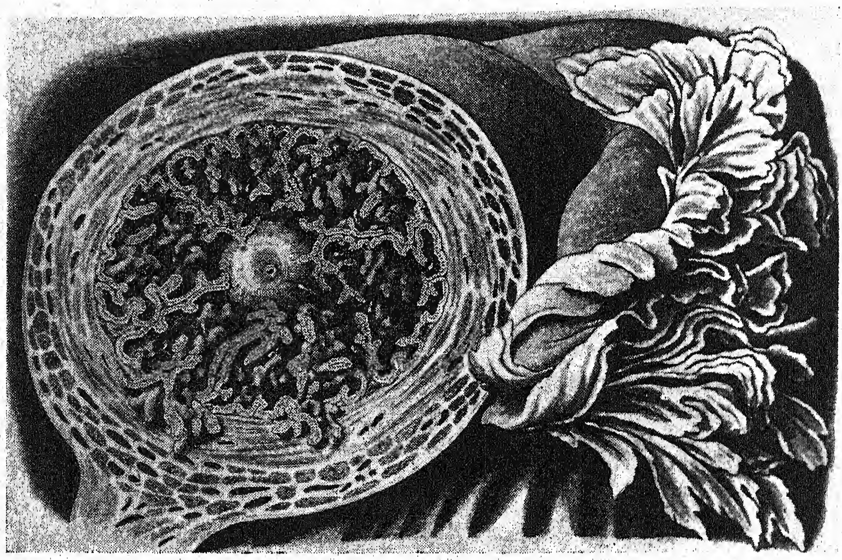


FIG. 441. *The beginning of a human life—the union, inside the oviduct, of one of the sperm cells of the male with an egg cell of the female. In each ejaculation of seminal fluid there are many hundreds of millions of sperm cells, each of which is an active, living organism, capable of fertilizing a female cell.*

Impotence. Like all bodily activities and movements, the erection of the penis and the ejaculation of the semen take place under the control of the nervous system. In the lumbar region, approximately at the level where a belt crosses the back, the spinal cord contains a nerve centre whose motor cells stimulate the dilatation of the corpora cavernosa and the expulsion of the semen by means of the wave-like contractions of the genital tube. This is known as the erection centre, and is indicated in Figure 452 under the lowest arrow in the spine. The centre is controlled by the cerebral cortex, which in turn is stimulated by sensory impressions and imaginary ideas as well as by hormones. In short, the erection of the penis is the result of the co-operation of a large number of widely separated, independent organs, and anyone who has understood the functioning of this delicate mechanism will understand how easily it can be influenced by disturbances of all kinds.

The inability of a man to carry out the sex act because the erection of his penis is too weak or entirely absent is known as impotence. It is

a widespread malady, which for very obvious reasons mars the lives of innumerable men and endangers or destroys countless marriages. There are various forms of impotence: genuine organic impotence due to the destruction or exhaustion of the erection centre in the spinal cord (almost always incurable), and the far more frequent psychological impotence, where the body is healthy, but is inhibited because of psychological reasons, such as fear, disgust, awkwardness and morbid ideas of sin.

II. THE FEMALE

THE basic plan of the female sex apparatus is represented diagrammatically in Figures 442 (anterior view) and 444 (lateral view). In each case the diagram faces a picture of the organs as they are to be found in the body; (a) indicates the two sex glands or the ovaries, (b) the oviducts, or tubes, which unite in the mid-line with the uterus (c). At (d) the latter opens into the vagina (e), which in turn communicates with the surface of the body (f). Here are to be found the external genitals: the clitoris (i), the labia minora and majora (g and h), and the vaginal entrance (f), half closed by the hymen. Parallel to the sex canal is the urinary canal, consisting of the bladder (l), the urethra (n), and the urethral orifice (o).

The External Genitals. The two lateral sex swellings which correspond to the male scrotum develop as two pairs of skin folds, the outer labia majora (h) and the inner labia minora (g). Since the two pairs of labia bridge the transition between the skin and the mucous membrane of the vaginal canal, the labia majora have the same colour as the skin, are dry, and are covered with hair, while the labia minora, because of their closer connection with the vagina, are covered with a moist reddish mucous membrane. The folds of the labia minora contain two glands corresponding to Cowper's glands in the male. They are called Bartholin's glands after their discoverer. During sexual excitement they produce a glairy mucus which wells forth between the labia and makes it easier for the male glans, which is also covered with mucus, to be inserted smoothly into the vagina. The urethral orifice (o) lies in the anterior upper corner between the labia minora. Above and in front of the urethral orifice lies the clitoris (i). The clitoris corresponds to the male penis, and like it the clitoris is filled with cavernous tissue which swells during sexual excitement, enabling it to emerge to a greater or lesser degree from its hiding-place. Similarly, the vaginal entrance is also padded with cavernous tissue (k), which swells during sexual excitement, thus narrowing the vaginal entrance.

The Hymen. Except for a central opening, the vaginal entrance is closed by means of a ring of mucous membrane called the hymen (f). The opening in the hymen is circular or elliptical. The size of the opening as well as the elasticity of the hymen vary greatly in different women. The hymen is a vestige of the animal past of the human race. In primeval times, when the

prehistoric ancestors of man still practised the animal form of copulation, where the male mounts the female from behind, the hymen, owing to its elasticity, served to press the penis against the clitoris during the sex act. After copulation, which was carried out in a standing position, it prevented the semen from flowing out of the vagina. This type of sexual intercourse probably did not cause a rupture of the hymen, particularly as we may assume that it was much more strongly developed in prehistoric times than it is at present, when it is usually torn during the first sex act.

The Vagina. The vagina is a tube of mucous membrane [Fig. 444 and Fig. 445 (e)], approximately 2½ inches long, which extends from the vaginal entrance (f) to the external os, the entrance to the womb (d). The wall of the vagina continually sheds cells that contain glycogen. By means of an enzyme the glycogen is

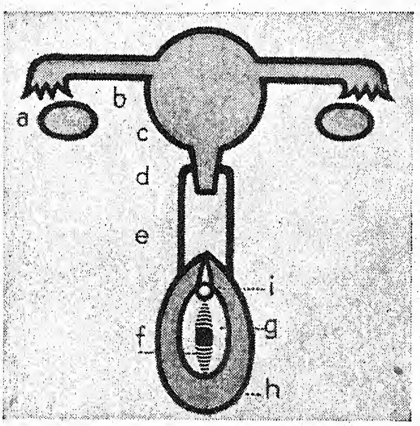


FIG. 442. *The arrangement of the female sexual organs, as viewed from the front. The separate organs are: (a) ovary, (b) oviduct, (c) womb, (d) neck of the womb, (e) vagina, (f) hymen, (g) labia minora, (h) labia majora, (i) clitoris. Compare this diagram with Figures 443, 444, and 445.*

broken down to grape sugar, which serves as a nutritive medium for bacteria. Bacterial activity leads to the formation of lactic acid, so that the vagina, like the stomach, contains an acid secretion. The lactic acid bacilli of the vagina, like those of the stomach, form a bacterial flora which hinders the growth of other bacilli and prevents pathogenic organisms of the external world from ascending to the upper sections of the sex canal. The bacterial flora of the vagina is a woman's best protection against infection. For this reason habitual vaginal douches, especially with disinfecting agents, are to be rejected as unnatural.

The lactic acid of the vagina is also of great importance for fertilization. Sperm cells are damaged by acids and consequently shun an acid environment. If a piece of vaginal mucous membrane is placed among living sperm cells, the latter soon retreat from the membrane, leaving it isolated. Alkaline mucus drips from the uterus into the vagina, as seen in Figure 445 (d), and attracts sperm cells. After the sperm cells have been deposited by ejaculation in the posterior portion of the vagina at (x^1), they flee from the acid vagina to the uterus, to which they are attracted by the alkaline mucus.

The Uterus. In order to obtain a plastic conception of the womb, no better model than a pear can be found. The uterus is a hollow, pear-shaped organ consisting chiefly of muscle fibres and lined with a mucous membrane containing many mucous glands. The broad massive portion (c) is called the body; the narrow part (d) is the neck. The uterus is suspended in the female pelvis with the neck downwards. The uterus is hollow. If a pear is

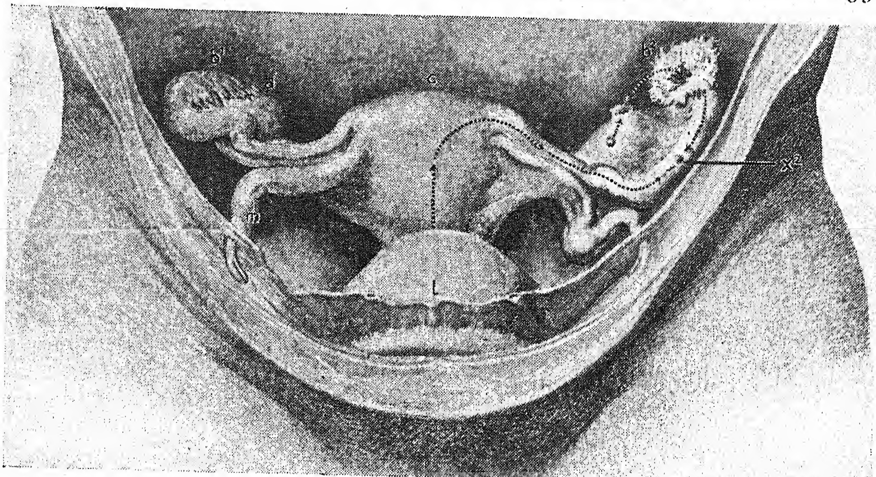


FIG. 443. *The internal female sex organs: (a) ovary, (b^1) and (b^2) oviducts or tubes, (c) womb or uterus, (m) the round ligament, which supports the womb. At (l) is the urinary bladder. By following the arrows near (b^2), the passage of the egg can be traced from the left ovary into the open infundibulum and along the oviduct to (x^2), where the egg encounters an ascending sperm cell and fertilization takes place. The lettering in this illustration agrees with that in Figs. 442, 444 and 445.*

cut open and the core removed one has a complete model of the uterus.

Pregnancy. The uterus is the first hotel at which we stop in the course of our earthly journey. The station from which we set out on our life journey was the ovary [Fig. 443 (a)]. Then we travelled over the cataract of the infundibulum (b^2) to the oviduct and were carried down the oviduct by the ciliary movements of the cells that line it. At (x^2) one of the most remarkable of all experiences occurred (Figures 432 and 441). We met a swarm of sperm cells which attacked us. One of the sperm cells, penetrating the egg, mixed its chromosomes with those of the egg, thus forming an egg-sperm cell. This was the moment of our true birth. Five minutes previously we were still the egg cell of a woman; at this moment, we became something quite different, a third being created by a man and a woman, a tiny human embryo, only $\frac{1}{50}$ as large as a grain of rice, but already a complete entity. We rested for a short while, then travelled slowly onwards, and finally arrived in the uterine cavity [Fig. 450]. Here we settled in one of the deep hollows of the mucous membrane, where we took root and established ourselves in the wall of the uterus. We grew, and because of the pressure of our growing body the uterus also grew larger. At the beginning of pregnancy the uterus is hardly as large as a woman's fist: about 3 inches long and weighing about 2.5 ounces. At the end of pregnancy it is as large as a pumpkin, extends from the vagina to the lungs, and weighs more than two pounds [Fig. 447]. The uterus grows by increasing its muscle substance. Each muscle fibre grows larger and gives off branches, so that by the end of the pregnancy the uterus consists of intricately and in-

geniously interlaced muscle fibres. At the same time the blood vessels increase in size and number until they surround the uterus like the serpentine locks of Medusa's head.

Birth. Imagine that someone has been able to grow an apple in a wine bottle and now wants to remove the fist-sized apple through the narrow bottle-neck without damaging it.

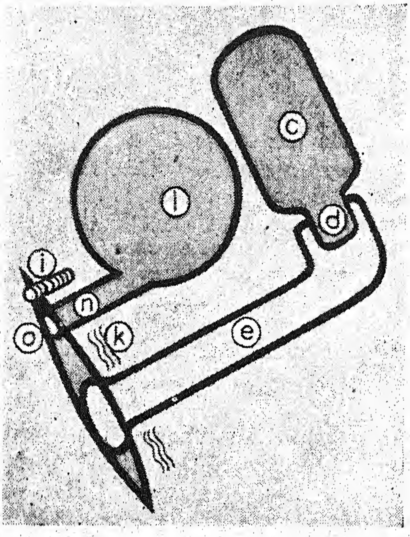


FIG. 444. *Diagram of the female sex organs as seen from the side. (c) Womb or uterus, (d) neck of the womb, (e) vagina, (i) clitoris, (k) cavernous tissue, (l) urinary bladder, with the urethra (n) and the urethral orifice (o).*

This appears technically impossible and it actually is impossible. Biology, however, is not technology. The uterus is able to accomplish the apparently impossible. The wall of the cervix, or neck of the uterus, contains numerous glands. During the last months of pregnancy they proliferate to such a degree that finally no more firm tissue is left, and the wall of the cervical canal becomes as porous as a sponge [Fig. 448 (e)]. Under the pressure of the uterine contractions, the child presses upon this sponge, making it as flat as a blotter (f). At the same time the uterus pulls it with every contraction just as one stretches a rubber band, so that in the course of four to ten hours the cervical canal, which is ordinarily as narrow as a knitting-needle, expands until it is wide enough to accommodate the child's head (g).

The Oviducts, or Tubes. From the uterus [Fig. 443 (c)] the two oviducts (b^1, b^2) pass laterally to the ovaries (a). The oviducts are two tubes, each about as thick as a pencil and approximately the length of a finger, lined with ciliated epithelium [Fig. 154]. The movements of the cilia serve to guide and to stimulate the movements of the sperm cells, since like fish in a stream they automatically oppose the current and consequently swim upstream. The egg, on the other hand, is carried downwards by the current. Any sperms that travel up through the uterus into the tube are attracted by the egg, and it is here that fertilization, the union of egg and sperm, takes place [Figs. 432, 441, 443 and 450].

The Infundibulum. The free, open ends of the tubes are widened to form ciliated funnels that resemble carnations. Perhaps it might be even more apt to compare them with sea-anemones, since the infundibula engulf the egg coming from the neighbouring ovary just as sea-anemones swallow their prey. When at rest [Fig. 443 (b^1)], the infundibulum lies on the ovary like a penwiper. When it becomes erect, as during intercourse, it forms an open goblet which produces a whirl-

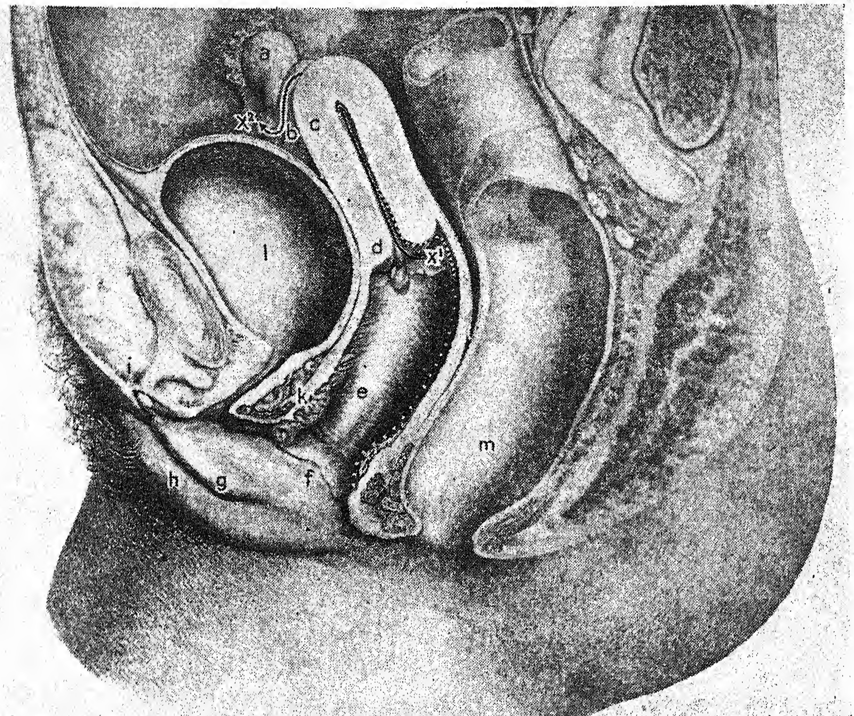


FIG. 445. *The complete female sex organs, seen in partial cross-section. They are: (a) ovary, (b) oviduct, (c) womb, (d) mouth of the womb, with the alkaline mucus plug, (x^1) spot where semen is deposited, (e) vagina, (f) hymen, (g) labia minora, (h) labia majora, (i) clitoris, (k) cavernous tissue; (l) is the bladder, (m) the rectum. The dotted lines at the edge of the vagina indicate the acid inferior and the alkaline upper areas. The arrows indicate the path followed by the sperm cells.*

pool by means of its ciliated cells and sucks in everything in its neighbourhood, including the egg (b^2). Our first experience on our journey through life is a daring leap from the ovary into a dark whirlpool.

Sterility and Extra-uterine Pregnancy. That this leap from the ovary into the oviduct is a daring one is proved by the accidents that occur at this very important starting-point of life's journey. In some women the leap of the egg cells is unsuccessful, because the ciliated funnel either does not produce enough of a current to suck in the egg, or does not open, or is situated too far from the ovary. Such women remain sterile. The egg which has lost its way now wanders aimlessly about in the abdominal cavity. Sometimes the sperm cells find it there, since they creep out of the upper end of the oviduct and are attracted to the egg. In ninety-nine out of one hundred cases the fertilized egg perishes in the abdominal cavity. It starves to death simply because it finds no place where it can settle. In rare, exceptional cases, however, it does settle somewhere and commences to develop (intra-

abdominal pregnancy). Much more frequent than an intra-abdominal pregnancy is a tubal pregnancy. The fertilized egg does not pass downwards into the uterus, but settles and takes root in the wall of the tube. Here it grows until it is approximately as large as a plum. Then the tube ruptures and begins to bleed. This bleeding is dangerous because the blood flows unhindered into the large abdominal cavity, and the rupture of the tube often causes only slight, insignificant pains. Some tubal tears may heal without any damage, indeed unnoticed, but many result in catastrophes.

The Ovaries. Near the tubes are the ovaries [Fig. 443 (a)]. These are two nodules as large as plums. The ovary consists of nothing but a mass of cells and several small blood vessels that enter the tissue from the

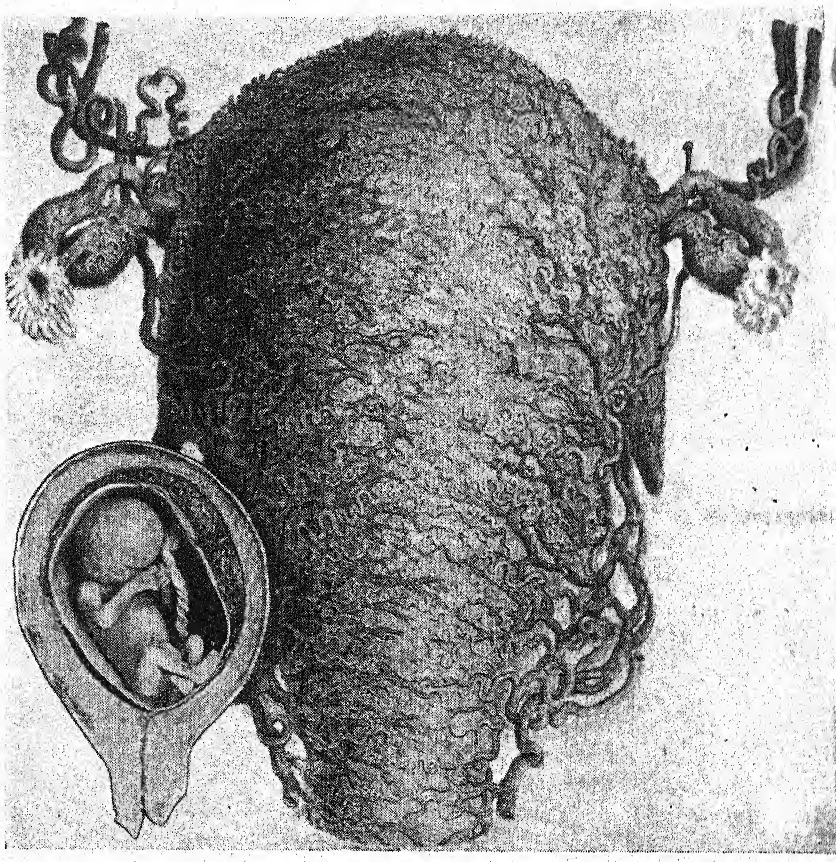


FIG. 446. *The human womb, or uterus, during pregnancy. The covering membrane has been removed, revealing the complicated network of vessels which supply the womb richly with blood. At upper right and left can be seen the ovaries and oviducts and the open, funnel-shaped infundibula, resembling sea-anemones. The inset shows the fœtus inside the womb. The umbilical cord can be clearly seen.*

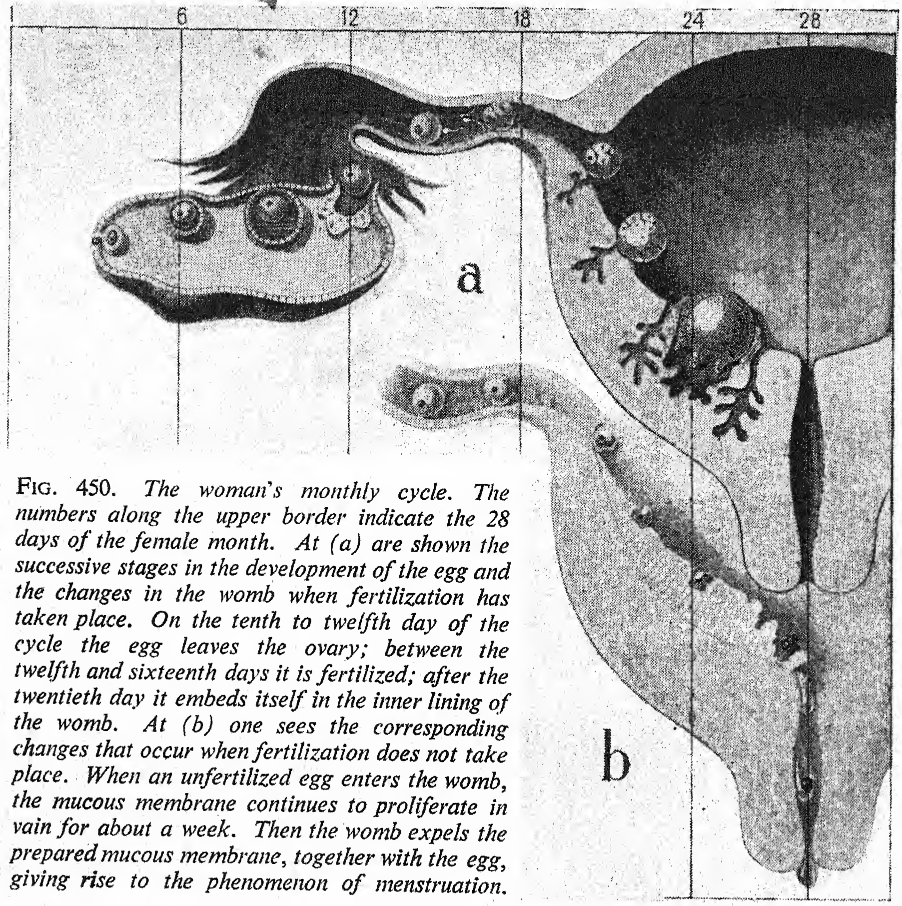
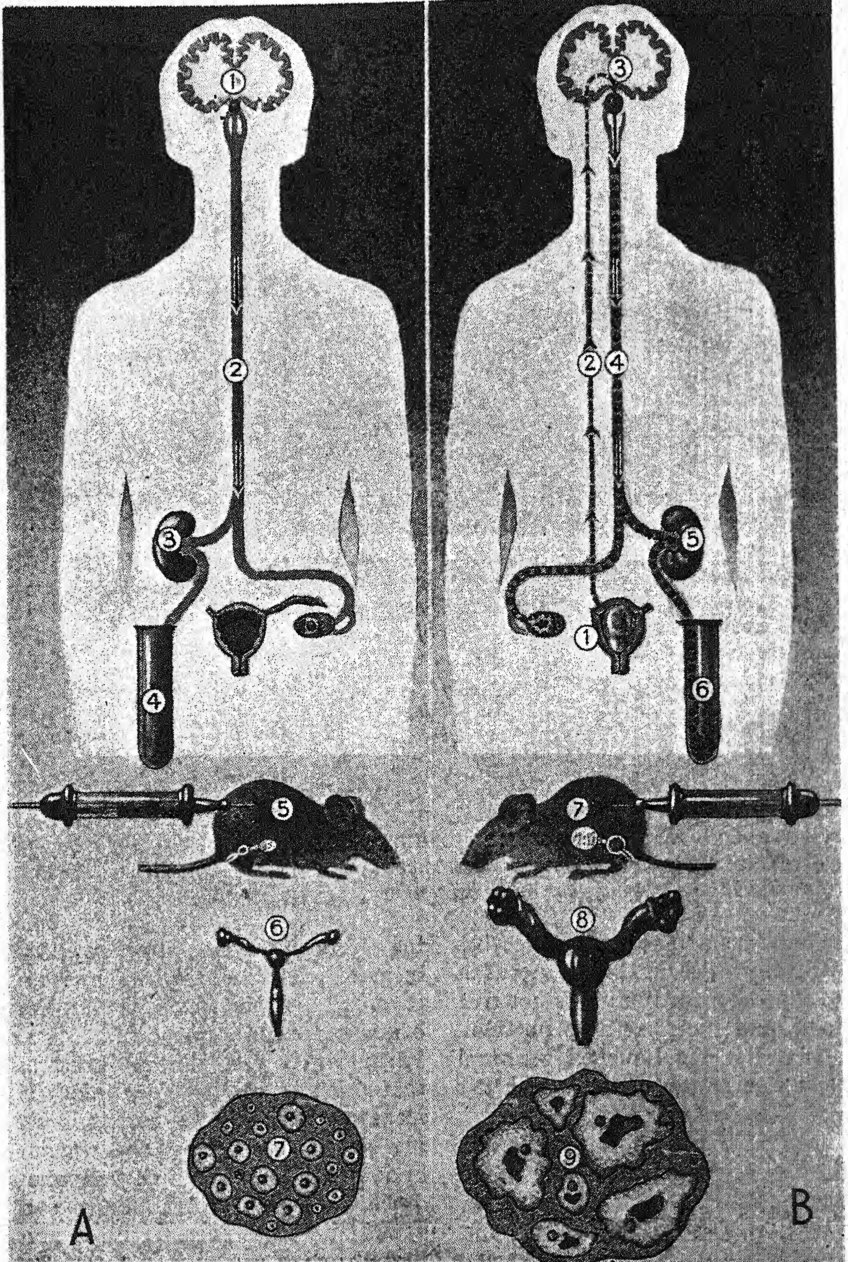


FIG. 450. *The woman's monthly cycle. The numbers along the upper border indicate the 28 days of the female month. At (a) are shown the successive stages in the development of the egg and the changes in the womb when fertilization has taken place. On the tenth to twelfth day of the cycle the egg leaves the ovary; between the twelfth and sixteenth days it is fertilized; after the twentieth day it embeds itself in the inner lining of the womb. At (b) one sees the corresponding changes that occur when fertilization does not take place. When an unfertilized egg enters the womb, the mucous membrane continues to proliferate in vain for about a week. Then the womb expels the prepared mucous membrane, together with the egg, giving rise to the phenomenon of menstruation.*

the menstrual blood [Fig. 450 (b)]. The fluid which leaves the uterus at the time of menstruation is not true blood, and therefore does not clot. It is rather the liquefied germinal membrane of the uterus, which has been discarded as useless.

Menstruation and Conception. The ovaries expel their eggs at intervals of approximately one month, so that the processes in the ovary and the uterus recur monthly. Because this cycle extends over a period of a month, the monthly bleeding has received the name "menstruation," from the Latin word *mensis,* meaning "month." The appearance of menstruation in a growing girl is an announcement by the body that the ovary has begun to produce eggs. Furthermore, menstruation indicates that the egg was not fertilized. If menstruation fails to occur following sexual intercourse, the woman knows that the egg which had wandered into the uterus about two weeks before has been fertilized and has settled in the uterine wall. Besides this "normal" cause, there are numerous other physical and psychological reasons for the non-appearance or tardiness of menstruation.

abdominal pregnancy). Much more ... cavity and ...



HORMONES: STIMULANTS OF THE SEX LIFE

FIG. 451. *The hormones, which promote and regulate sexual activity, are produced as a result of the complex interaction of the endocrine glands. (Page 606.)*

CHAPTER XLIV

Sex and Human Life

THE PERIODS OF MAN'S LIFE. THE HORMONES OF THE SEX GLANDS. THE HORMONAL DETERMINATION OF PREGNANCY. THE SECONDARY SEX CHARACTERISTICS. THE DUAL NATURE OF SEX. HERMAPHRODITISM. CASTRATION. SEX TRANSFORMATION. REJUVENATION IN THE LOWER ANIMALS AND IN MAN. THE TRUE PROBLEM: NOT REJUVENATION BUT AGEING. THE FUTURE OF HUMAN BIOLOGY.

THE influence of the sex gland on the body and mind of man is so decisive that human life can be divided into periods according to the functions of the sex gland. Youth implies immaturity of the sex gland; maturity is the period during which the gland functions; old age begins when the sex gland stops functioning. Youth and age are thus to a very large degree determined by the sex gland.

The Hormones of the Sex Glands. The maturation of the sex cells is accomplished by the production of hormones by the sex glands. The testicle produces a male sex hormone, the ovary a female hormone.

Fertilizing Action

The Male Sex Hormone. The sex hormones produce local (sex apparatus) and general (entire organism) effects. The action of the hormones on the sex apparatus may be compared to that of a fertilizer. Without them the sex apparatus remains undeveloped, dry, sterile. Figure 452 is a diagrammatic representation of the action of the male hormone. The system of endocrine glands—pituitary, thyroid, and adrenal—acts on the sex gland and stimulates the production of the sex hormone (1). The latter is distributed throughout the body by the blood-stream (2). It sensitizes the cerebral cortex so that it is receptive to erotic stimuli, and from the cortex the nervous stimuli pass through the spinal cord (3) to the sex apparatus, which is activated.

Change of Function

The Female Sex Hormones. The female sex hormones have furnished us with completely new and extremely astonishing insights into the mechanics of the vital processes. There is an entire series of female hormones, of which the most important are the pituitary growth hormone, the egg-maturation hormone of the pituitary, the follicular, pregnancy and corpus luteum hormones.

The Pituitary Growth Hormone. The female sex functions are also controlled by the pituitary. In youth the pituitary secretes growth hormones. After having developed under the control of these hormones, the body must now carry out its reproductive function. Consequently the pituitary switches on a new function, and instead of the growth hormone it now secretes a hormone

for the maturation of the sex cells.

The Egg-Maturation Hormone of the Pituitary. Since this hormone stimulates the maturation of the eggs in the ovary, it is called the egg-maturation hormone [Fig. 451 (A), (1) and (2)].

Preparing a Nest

As occurs in the case of almost all hormones, excess quantities of egg-maturation hormone leave the body with the urine [A (3, 4)]. If the urine of a sexually mature woman is injected into young mice [A (5)] whose ovaries are still quiescent, eggs ripen in the ovary in two days [A (7)]. The sex apparatus itself [A (6)] changes very little.

The Follicular Hormone. Under the influence of the pituitary hormone an egg develops. The interior of the growing egg ball liquefies, thus transforming the ball into a vesicle, the follicle [Fig. 449 (6-8)]. The hormone is absorbed by the blood vessels and conducted to the uterus by the blood-stream. Here it causes a proliferation of the mucous membrane, thus providing a nest for the maturing egg, as represented in Fig. 450.

A Potent Secretion

As described on page 602, each ripening egg reserves a nest in the uterine hotel before entering upon its life journey! This nest formation is vitally important, not only for the egg but for the entire human race. Consequently, the nest-forming hormone is one of the most powerful substances that we know; with one gramme of follicular hormone 35 million virgin mice can be excited sexually!

If the egg arrives in the uterus without having been fertilized, it does not need the cradle which it has ordered, and the cradle is expelled from the body as the menstrual flow. On the other hand, if the egg is fertilized and settles on the uterine wall, the further arrival of eggs must be prevented, because the uterine hotel is now occupied.

Pregnancy Hormones. The embryo in the uterus [Fig. 451 (B), (1)] sends a report (2) to the pituitary, the central control station for the functions of the ovary, that the uterus is occupied. Under the influence of this report, the pituitary hormone is transformed and now works in an opposite manner on the ovary. It inhibits the formation of any more eggs. The emptied follicle of the last egg to emerge is transformed into a firm yellow body called the corpus luteum [Fig. 449 (9, 10)].

Infallible Test

The Hormonal Determination of Pregnancy. If a woman's urine is injected into a virgin mouse [Fig. 451 (B), (7)] and hæmorrhagic follicles or corpora lutea (9) are found in the animal's ovaries when it is opened, then one can say with absolute certainty that this woman is pregnant. This test is based upon the fact that if an embryo is present in the woman's uterus, the pituitary secretes a hormone which inhibits the maturation of any further eggs. This test is known as the Aschheim-Zondek pregnancy test. However, since the Aschheim-Zondek test requires one hundred hours, a number of modifications has been made. The best one is the Friedman test, which is just as reliable as the original one.

The Corpus Luteum Hormone. However, the hormonal activity of the female sex gland is by no means

at an end. Like its predecessor the follicle, the corpus luteum also acts as an endocrine gland. By means of its hormone, the egg follicle (the hormone gland of the non-pregnant female) prepares the uterus for the egg. By means of its hormone, the corpus luteum (the hormone gland of the pregnant female) takes care of the embryo by participating in the formation and development of the placenta. The hormone of the corpus luteum is thus a pregnancy protection hormone. If the corpus luteum is destroyed the child dies in the uterus.

Preparation for Mating

The Secondary Sex Characteristics. The aforementioned actions of the sex hormones, despite their great variety, do not suffice for the fulfilment of their task. Before an egg can settle in the uterine wall it must have been fertilized, and in order for fertilization to have taken place the woman must have cohabited with a man. In order to bring about this act, the body is equipped with a number of physical and mental characteristics, which, in contrast to the primary sex differences in the structure of the sex organs, are known as the secondary sex characteristics.

Sexual Display

The secondary sex characteristics constitute, so to speak, the advertising department of the firm called "Man." By means of these signs of sexual maturity the world is informed that sex cells, even though they cannot be seen, have become mature within the body. Like any good advertisement the body is made as attractive as possible. Flowers are nothing but the advertisements

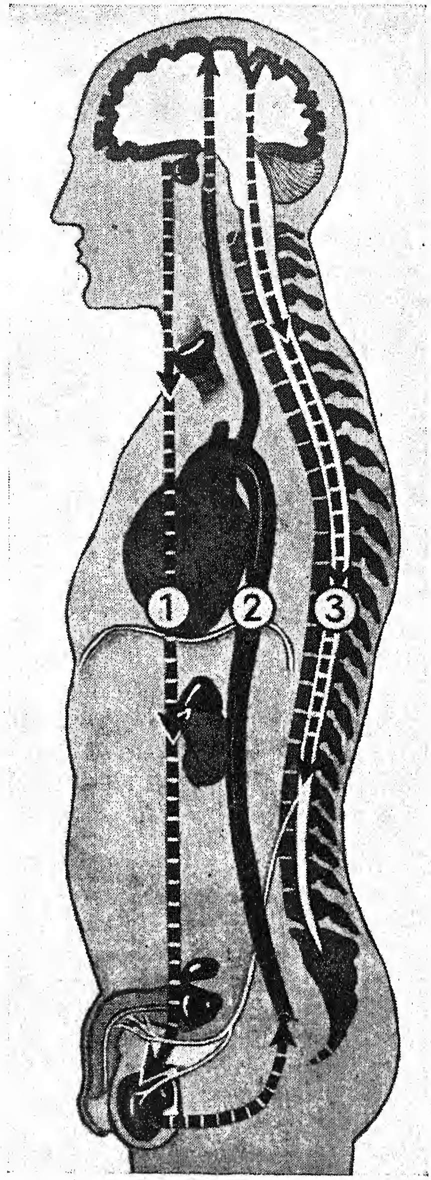


FIG. 452. *The endocrine glands (pituitary, thyroid, adrenal) activate the sex gland, stimulating it to produce sex hormone (1). Distributed by the blood (2), the sex hormone sensitizes the cerebral cortex, which in turn activates the sex organs through the spinal cord (3).*

ominal p

of plants, which, by means of their colours, forms, odours, etc., attract the insects which are the travelling salesmen of the plant world. Similarly, many animals and birds never appear more beautiful and seductive than when in their so-called "mating dress."

In order to prevent members of the opposite sex from passing these attractions without exhibiting any interest, the hormones awake in the brain an impulse akin to hunger, which in the male is directed towards an evacuation of the sex glands and in the female towards the reception of the sex cells.

Reaching Maturity

Similarly, therefore, the secondary sex characteristics of man and woman are not identical; on the contrary, each sex lacks the characteristics of the other, so that each sex feels incomplete without the other and desires to unite with it as the natural complement of its own imperfect being.

The Secondary Sex Characteristics of the Woman. When the first eggs begin to mature and to form follicles in the body of a growing female child, the body of the girl begins to mature under the influence of the follicular hormone. By means of a process of transformation the "indifferent" child's body becomes that of a woman. The breasts swell, and fat is deposited on the shoulders and hips, giving the rounded contours of a sexually mature woman. Hair begins to grow in the armpits and on the pubis, while the hair of the head grows long. Internally the body is developed as a cradle for the child; the pelvis becomes broad and the abdomen large. Owing to the broadening of the pelvis and the shortness of her thighs, the woman is normally knock-kneed and her thighs touch because of the accumulation of fat tissue. Consequently, in a standing woman there is no space between the thighs such as can be seen in a man.

Man's Active Rôle

The Secondary Sex Characteristics of the Male. The action of the male sex hormone is very different. The man is intended to seek the female and to impregnate her in the course of the sex act. The effect of the male sex hormone is therefore an activating one. A woman attracts and wishes to be conquered; the man is aggressive. In contrast to the woman, the man's thighs become long, his pelvis remains narrow and his abdomen small, but his chest and shoulders become broad. The thighs do not touch, but leave a small space free between them. The man's accumulation of fat tissue is slight, since it is suppressed by the testicular hormone, so that men generally remain wiry during the period of sexual maturity and do not begin to exhibit adiposity until the beginning of old age. The man's skin glands do not function as actively, the hair on his head remains short, but instead he develops a beard.

Male and Female

The Dual Nature of Sex. A child arises from the union of a male sperm and a female egg cell. The egg-sperm cell is half paternal-male and half maternal-female. Since the body develops by continued division of the original egg-sperm cell, an individual human being is simultaneously both male and female. Mathematically speaking, a human being is not a whole number, but rather a

fraction having the form $\frac{M}{W} = \frac{\text{Man}}{\text{Woman}}$. Men are beings in whom M predominates, while W predominates in women. There is no absolute man with the formula $\frac{M}{W} = \frac{100}{0}$, just as there is no absolute woman with a formula $\frac{M}{W} = \frac{0}{100}$. There are female elements in every man, just as male characteristics may be found in the sex glands of both sexes. In many lower animals the glands of both sexes develop alongside each other. Earthworms, snails, oysters, and leeches are hermaphrodites. In chickens one generally finds a rudimentary testicle near the ovary, and in all mammals, including man, the sex gland is very often accompanied

FIG. 453. *These two portraits are of the same person—the celebrated hermaphrodite Chevalier d'Eon, who for the greater part of his life masqueraded as a highly feminine and very attractive woman, and hoaxed the world as such. But whenever he appeared in his proper guise as a man, it was as a brave officer, a noted duellist and an extremely able diplomat with a reputation for astuteness. Truly, an enigma of sex!*

every woman. A man has mammary glands, and even a uterus as large as a grain of rice; while the female clitoris is an undeveloped form of the male penis. If a man receives an injection of ovarian hormone, his "uterus" becomes enlarged; and if testicular hormone is administered to a woman, her clitoris grows larger.

Hermaphroditism. The embryo exhibits its dual sexual character in that it has the rudimentary forms of by more or less well-defined elements belonging to a gland of the opposite sex. If these glandular elements of the opposite sex should develop to such a degree that their existence becomes manifest, either directly or indirectly, in that the characteristics of the opposite sex become pronounced—for example, large mammary glands in a man—the individual is then described as a hermaphrodite, so called after a son of

Hermes and Aphrodite, who was so desired by the nymph of a fountain that the gods united them to form one person. Genuine hermaphrodites with both testicles and ovaries are rare exceptions. On the other hand, it is not uncommon to find children whose external genitals exhibit such a combination of male and female

FIG. 454. *Maternal love from ampoules! This virgin female monkey became so maternal as a result of the administration of pituitary hormone that, contrary to monkey habits, it adopted a guinea pig. After removal of the sex glands, however, its mother love disappeared completely.*

structures at birth that it is often difficult, if not impossible, to decide whether the infant is a boy or a girl. A child may be born with the closed genital cleft of a boy, but the ostensible penis is small like a clitoris, and the sex glands cannot be found because they have remained within the abdominal cavity. Or, on the other hand, two glands may have become prominent like a boy's testicles, but the genital cleft may remain open like a vagina, and one faces the question as to whether the child is a girl with descended ovaries or a boy whose scrotum has remained open. A child whose sex is uncertain at birth should not be assigned to a definite sex group capriciously and hastily. Instead, it should be classed as a child of uncertain sex and should be examined every year by a specialist. Generally the sex of the individual can be determined in the course of childhood by means of conscientious observation, and the child should then be introduced into its true sex group despite any previous type of training which it may have received. Unless this is done, one cannot be sure that unpleasant surprises will not occur.

Girl into Boy

In a typical case, a child with indeterminate genitals is raised as a girl and behaves as such during childhood. At the age of thirteen, however, the voice suddenly becomes an octave lower, a beard begins to grow, and—the girl becomes a man. The glands that remained within the abdomen were not ovaries, but testicles. Or, conversely, a boy who apparently has two "testicles" in his scrotum begins to show signs of mammary development and to display female tendencies at the age of fourteen: the boy is really a girl. Errors of sex determination are not as uncommon as one might at first assume, and the relevant literature contains life histories, as interesting as they are tragic, of persons who suffered for many years or even throughout their entire lives

because of a false determination of sex.

Perhaps the most celebrated case of a hermaphrodite, who played in turn the rôles of both man and woman with equal success, is that of the Chevalier d'Eon, who was born in France in 1728.

An Enigma of Sex

Although brought up as a boy, he began to wear his sisters' dresses from the age of ten, and appeared more attractive in them than they did. A countess took the good-looking boy into her home, and later introduced him to the court in the guise of a girl. Louis XV fell in love with this "girl," who was as clever as "she" was unusually beautiful. In 1755 the "Chevalière" d'Eon went to St. Petersburg as the "niece" of a diplomat. At the Russian court "she" acted as reader to the Empress Elizabeth and took part in numerous adventures. Later, d'Eon was again sent to Russia in male dress, as the brother of the "beautiful demoiselle." As an officer in the French army he was wounded and received several decorations, and in 1762 he was sent to London as French ambassador.

"Madame d'Eon"

When Louis XVI ascended the throne, d'Eon's enemies had him dismissed and he was compelled to describe himself publicly as being of female sex and to wear woman's clothes. Hitherto known as a brave officer, feared as a duellist, and regarded as a capable diplomat, d'Eon suddenly appeared to the boundless astonishment of London and Paris as a mature but still charming woman. From that time onwards he lived quietly in London, on the best of terms with society, and he died in 1810 at the age of eighty-three. At the instigation of a number of betting-houses which had accepted bets upon d'Eon's much-disputed sex amounting to more than one million pounds sterling, the body was medically examined after death and "Madame" d'Eon was found without question to have been a man.

Castration. If an animal is deprived of its sex gland by castration, it not only becomes sterile, but also loses its secondary sex characteristics. A rooster ceases to crow and loses its plumage and comb; the sex impulse disappears, as well as the desire to fight, and it becomes a capon. A fiery stallion becomes a quiet gelding, and an intractable bull becomes a patient ox.

Eunuchs

In more uncivilized times castration was also common among men. In the Bible and in the *Iliad* we read that the conquered enemy was castrated and the severed organs were thrown to the dogs. During the uprising of the Sicilians against the French in 1282—the so-called Sicilian Vespers—the rebels castrated all the men who fell into their hands. In China and Turkey until modern times children were castrated in order to produce eunuchs who would later be reliable harem guards. In Italy until the middle of the nineteenth century one could still see signs in the barbers' shops: "Castration performed cheaply here." Children were castrated in order to sell them, according to the custom of the period, as obedient servants, as actors, or choir singers.

The administration of sex hormone to a castrated animal, or the implanting of a sex gland, is followed

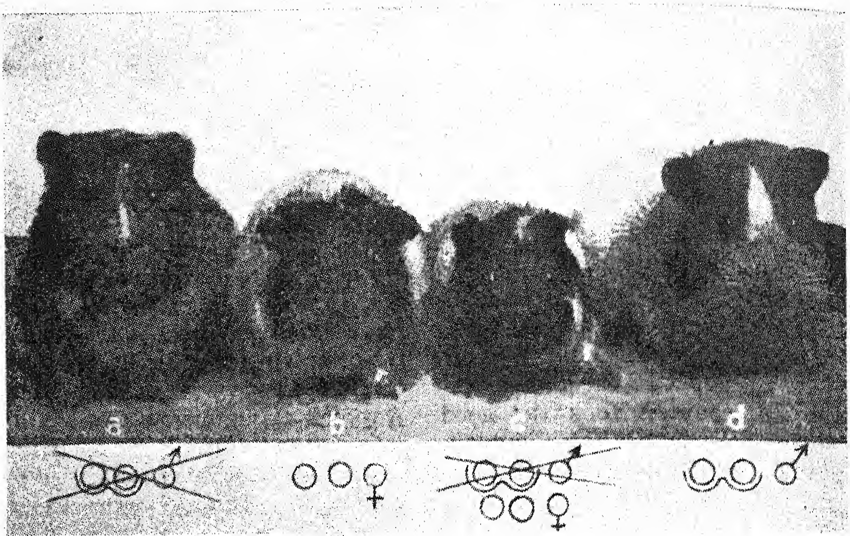


FIG. 455. *Man experiments with sex—an example of Steinach's celebrated researches. Here are four guinea pigs from the same litter: (b) is a normal female, (d) a normal male, while (a) and (c) are two castrated males. Ovaries have been implanted into the castrated (c), which previously was an over-grown, bloated pseudo-male, like (a). The artificial female (c) became smaller and more delicate and timid—became, in fact, more feminine than a true female, such as the animal (b) beside it. Furthermore, it grew more excitable sexually than its litter mates, but since it had neither vagina nor uterus, its love play and maternal feelings could find no natural means of expression and remained fruitless.*

by the appearance of the secondary sex characteristics. The troublesome symptoms experienced by women whose ovaries have been removed are relieved by the administration of ovarian hormone. Similarly, women in the menopause, who suffer physically or mentally because of the deficiency of ovarian secretion, are treated with hormone preparations.

Implanted Glands

Sex Transformation among Animals. If one implants an ovary in a rooster or a testicle in a hen, the implanted gland is rapidly destroyed by absorption and sloughing. But if the rooster is castrated and an ovary is then implanted, it remains and grows within the body, and the rooster is transformed into a hen under the influence of the ovary. The animal acquires the plumage of a hen, exhibits female behaviour in relation to other roosters, and if placed upon eggs it acts like a brood-hen.

The effects produced by the artificial administration of hormones, or by the implantation of glands, exceed those found in nature. Just as one can produce light which is stronger than sunlight by means of an artificial sunray lamp, so one can feminize or masculinize animals much more markedly, or stimulate in them much stronger impulses than are normally observed, by means of hormones or implanted glands. Figure 454 shows a virgin female monkey, in which, however, the sex organs, breasts, and maternal

instinct were prematurely developed by injections of pituitary hormone. In order to satisfy her mother love, she took a young guinea pig from a litter and nursed it tenderly as her foster-child. Her mother love was extravagant, as indicated by the expression on her face in the picture. But when this monkey was deprived of her sex glands, she lost all interest in the young guinea pig and watched unconcernedly, without any demonstration of maternal feelings, while it was killed by another monkey.

Feminization

Figure 455 shows a litter of guinea pigs: (d) is a normal male, and (b) a normal female; (a) is a male whose testicles have been removed, and (c) a male whose testicles were also removed, but who then received an ovarian implant. Not only did this male become feminized, but it was even more feminine than (b); it was distinguished from its "sex comrades" by its extremely delicate body structure and markedly feminine behaviour! On the other hand, if a testicle is implanted in a castrated female, she displays more masculine characteristics than does a genuine male!

Sex Transformation in Man. In man the conditions are essentially the same. The male and female sex glands, as well as the male and female hormones, are antagonistic in their actions. If a female sex gland is implanted in a man, it is rapidly destroyed, and the same thing happens to a testicle implanted in the body of a sexually mature woman. Nevertheless, throughout its entire life every organism retains some genital tissue belonging to the opposite sex. It is quite likely that women who exhibit masculine characteristics, such as broad shoulders, long legs, a deep voice, and some tendency towards beard growth, possess some functioning testicular tissue. When the sex gland becomes weak, in the course of the ageing process, it sometimes happens that the tissue of the other sex begins to predominate.

FIG. 456. *An outstanding case of masculinization. This photograph is of a woman, previously quite feminine, in whose body a tumour composed of testicular cells has developed. Her body has become flooded with male hormone, and she now resembles a man with coarsened features and a strongly developed beard.*

This explains the well-known fact that after the menopause women become masculinized to some degree by developing facial hairiness and acquiring coarser masculine features, a deeper voice, and a gruff manner. Figure 456 shows a striking case of masculinization. Until a few years before, this woman had been quite feminine. One day, however, a tumour developed in her body. This tumour was due to a proliferation of the cells which belong to the opposite sex, and which now flooded the woman's body with male hormone.

The Rejuvenation of Animals. An ageing creature is an organism which is slowly castrated by nature by exhaustion of the sex gland. If one implants an active sex gland in an aged animal, the youthful secondary sex characteristics return. The animal has been rejuvenated by its new sex gland.

Recapturing Youth

Thus a rat normally grows old between the ages of eighteen and twenty-three months. Its fur becomes scrubby and the skin may become denuded of hair in patches; the eyes become dull, appetite vanishes, and the sex impulse disappears [Fig. 457 (a)]. If an active testicle is implanted in such an animal, the hair begins to grow again, the appetite improves, the animal gains weight, it becomes active again, and the sex impulse manifests itself once more (b). Steinach succeeded in rejuvenating an old female rat which had long since lost its natural fertility, so that it allowed itself to be impregnated once more and bore young which it suckled. When its normal life-span had been reached and its brothers and sisters died off in rapid succession, this female rat continued to live and survived its generation by a full eight months.

New Glands for Old

Stated, for comparison, in terms of human life, these figures mean that it lived 120 years instead of 80 like its brothers and sisters. The same results were obtained with old dogs and goats which were so weak that they could no longer stand. As a result of repeated transplantations of active sex glands they became rejuvenated to such an extent that they were able to have young again.

Rejuvenation of Man. Theoretically the problem of rejuvenation in man is subject to the same conditions as in animals; practically, however, the prospects are not nearly so favourable. An experimental animal is patient. It allows itself to be selected from among hundreds of cases as being " suitable for rejuvenation "; it allows itself to be operated upon once, twice, even three times, and is thrown into the waste-pail without any further ado if the experiment fails. Photographs of the unsuccessful cases do not appear in the scientific journals; only the outstanding cases, the more or less successful cases of the entire series, are selected for presentation. Nor do the published photographs always inform one of the permanency of rejuvenation.

Brief Respite

Generally speaking, rejuvenation is of short duration, since an aged body is a poor nutritive medium for a young gland, so that the regained youth generally vanishes together with the gland in a few weeks, whereupon the organism breaks down twice as fast. In an animal which has a short life-span anyway, the short duration of success does not weigh so heavily as in man, who demands a period of rejuvenation lasting for at least several years. It is naturally easier to rejuvenate an eighteen-month-old rat so that it will have an apparent age of twelve months than it is to reduce the age of a human being from eighty-six to sixty-six. Then again, there is the difficulty of accumulating sufficient experience, since one cannot perform hundreds and thousands of all sorts of experiments, as one does with animals, until the best method has

been found. Furthermore, it is difficult to obtain the necessary number of old people who, with the consent of their families, will submit to experimental operations, just as it is also difficult to have a sufficient supply of healthy, youthful glands at hand at all times. Consequently both experience and success in the rejuvenation of human beings still lag far behind animal experiments. Finally, man is an animal organism—but he is not an animal. A man of eighty, exhausted physically and mentally by hard work, suffering, and the diverse experiences of a lifetime, is a quite different and much more unfavourable subject for rejuvenation than a goat in a stall, which has grown old between the manger and the pasture.

The True Problem: Not Rejuvenation, but Ageing. The true problem of human biology is not rejuvenation, but ageing. The majority of modern human beings do not even reach the point where they need rejuvenation, since most people do not become old. They die before they have become old. Modern man does not grow old normally like an animal, in which there is a general, even ageing of all the organs. Man ages unevenly; individual organs become old sooner than others because they are always under a strain due to the erect position of the body and the mode of life under civilized conditions. The result is that the vital machine is brought to a standstill prematurely. The causes are almost always the same: calcium is deposited in the tanks and pipes of the body machine; the joints wear out; the cardiac pump slows down; the arteries become brittle and break. The immediate task of human biology is not to rejuvenate old people,

FIG. 457. *The miracle of rejuvenation. At (a) is an aged, feeble and partly bald male rat, whose sex impulse has become exhausted. After the implantation of an active male sex gland, its youthful appearance and much of its vigour returned (b); it was able once more to impregnate females, and fathered several litters.*

but to ensure that everybody can grow old normally. Not rejuvenation but ageing! Through the magnificent successes of medical science it has been possible to extend the average life-span to the decade between sixty and seventy. The average life expectancy of man has risen from about thirty years to over sixty. It is the future task of human biology to extend the life expectancy to a much more extended limit still.

The Future of Human Biology. The knowledge that it is unnatural to die of "diseases of old age" between the ages of fifty and seventy-five must be spread far and wide. The natural limit of human life is between the ages of eighty and ninety, nor is there any evidence that it would not be possible to increase the average life-span beyond this apparently natural limit. If during the coming fifty years mankind

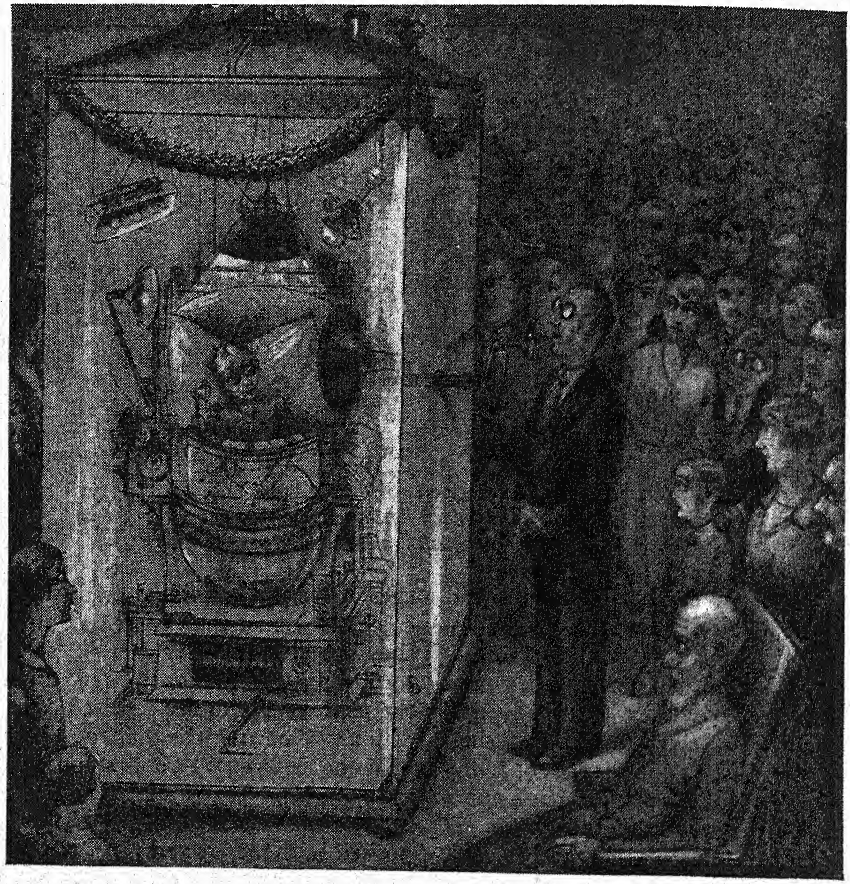


FIG. 458. *The false ideal. A caricature on the attempts of some scientists to prolong human life artificially. "Great-great-great-grandmother is awakened for ten minutes on the celebration of her two-hundredth birthday, in order to receive the congratulations of her numerous descendants." True scientific progress does not lie, however, in the direction of prolonging life after the capacity to be happy and useful has departed.*

FIG. 459. *The true ideal—happy and healthy old age. The elimination of disease and suffering and the extension of human life under normal and natural conditions—these constitute the most worthy goal for the medical science of the future.*

were to employ for the creation of life-conserving apparatuses only a fraction of the energy and the money that have been expended during the past fifty years upon the building of life-destroying machines, the extension of the human life-span, which appears utopian today, would be a fact tomorrow. The medical science of the past solved the problem of protecting life against epidemic disease. Just as Hamlet says: "What's Hecuba to him . . ." so we moderns say: What are smallpox, plague, and cholera to us? And tomorrow we will say the same of the few still remaining pandemic diseases: What are diseases to us? Only the ghosts of yesterday.

Through the centuries, medical science has rescued human life from the grasp of the angel of death. Now its task is to conserve this life which it has saved until it reaches its natural end. What does humanity lack? An armament industry—not for the destruction, but for the conservation, of man's life. And then, in the words of Genesis, "his days shall be an hundred and twenty years."

THE END

Nature does not allow us to explore her sanctuaries all at once. We think we are initiated, but we are still only on the threshold.

SENECA.

Glossary

of medical and technical terms not explained in the text

Abraded, scraped, injured by rubbing.

Adipose, fatty.

Algæ (*singular,* alga), an order of non-flowering, mainly aquatic plants, including the seaweeds.

Alveolar, pitted, resembling a honeycomb; made up of sockets or *alveoli* (*singular,* alveolus).

Analgetic, producing insensibility to pain.

Annular, in the form of a ring.

Antipyretic, intended to prevent or counteract fever.

Antithetical, contrasting, directly opposite.

Aplanatic (of a lens), free from spherical aberration.

Arboriform, shaped like a tree; divided into branches.

Arborization, branching out, producing a tree-like effect.

Articulation, a joint, a connection between two parts enabling them to move in relation to each other.

Atom, the smallest particle of matter which can enter independently into a chemical relation with another atom to form a molecule (*q.v.*).

Atonic, lacking in tone or tonus (*q.v.*).

Atrophy, wasting away, degeneration through disuse.

Autolyse, to break down, destroy; said of the destruction of body cells by serum.

Avascular, the opposite to vascular (*q.v.*); without circulatory vessels.

Axilla, the armpit.

Biogenetic, concerned with the origin and development of life in general or of new species.

Bipartite, divided into two parts, twofold.

Blastula, the stage in the development of the fertilized egg-cell at which it subdivides into a number of separate cells to form a hollow sphere.

Bolus, a mass or ball of food swallowed in a single act.

Bursæ, pockets, purse-like cavities.

Calcification, impregnation with, or conversion into, chalk.

Capillary, resembling a hair; a small hair-like blood vessel.

Capsule, an enclosing or covering membrane.

Cardiac, relating to the heart.

Carnivore, a flesh-eating animal.

Cell, the primary unit of all living matter, whether animal or plant. Cells vary greatly according to their function and the being or organ to which they belong, but every cell contains a nucleus (*q.v.*) and is bounded by a membrane through which some, but not all, substances can pass.

Centrosome, or central body, a small body within a cell which plays an active part in the division of the cell.

cg. (centigramme), the one-hundredth part of a gramme.

Chromatin, a substance found in the nucleus of a cell, with an affinity for stains, which carries the cell's hereditary qualities.

Chromosome, a tiny rod formed in a cell by the breaking up of the spireme (*q.v.*) during cell division (see p. 10).

Cilia (*singular,* cilium), minute processes (*q.v.*) on the surface of a cell resembling hairs.

cm. (centimetre), the one-hundredth part of a metre.

Colloid, a jelly-like, non-crystalline substance, such as gelatine, which when suspended in solution does not pass through a membrane.

Compulsive, constrained, not under voluntary control.

Concretion, a solid mass of organic matter, usually formed by the addition of lime salts.

Contractile, able to contract or shorten.

Convoluted, coiled, arranged as a spiral.

Convolution, twist, coil, single turn of a spiral.

Corona, a halo, a circle.

Cytoplasm, the material of which the part of a plant or animal cell surrounding the nucleus is made.

Dermal, relating to the skin, especially to the true skin or corium beneath the epidermis.

Dextrin, the gummy matter of starch, from which it is separated by heating.

Diastole, the rhythmic expansion of the heart, whereby the latter is filled with venous blood; the opposite of systole (*q.v.*).

Dilatation, expansion, widening out.

Diuresis, the passing of urine, especially when in excessive amount.

Ectoderm, the outer primary germ layer of the germinal disk (p. 18).

Edentulous, toothless.

Electron, the ultimate structural unit of matter; a particle of electricity with a negative charge, which circulates in an orbit round the nucleus of the atom (*q.v.*).

Element, one of the 92 primary kinds of matter of which all material things are composed.

Embryogeny, the process of development of an embryo, or the science dealing with that process.

Emulsion, the union of a fatty material with water or another liquid, so that the fat is suspended in the liquid without dissolving.

Encapsulated, enclosed in a capsule or covering membrane.

Endemic, said of a disease which is commonly found in and is confined to a particular locality.

Endoderm, the inner primary germ layer of the germinal disk (p. 18).

Epithelial, relating to the epithelium, or tissue covering the intestinal canals, blood vessels, mucous membranes, etc.

Extractive, of the nature of an extract, or substance removed from a solution.

Fertilization, the impregnation of an ovum or egg-cell by a male sperm-cell, rendering the former capable of development into a new individual of its species.

Fibrillation, the twitching or irregular contraction of muscle fibres, especially those of the heart.

Filtrate, a liquid that has been passed through a filter.

Flaccid, flabby, limp, yielding.

Flatulence, excessive accumulation of gas in the intestines.

Furuncle, a boil, a small inflamed tumour.

Gastrula, the germinal disk formed by the flattening of the blastula (*q.v.*) till its opposite walls meet (p. 18; Fig. 15).

Gastrulation, the formation of a gastrula (*q.v.*)

Gene, the presumed unit of heredity: a body in, or a section of, a chromosome that governs the transmission of a particular character or group of characters from one generation to the next.

Glairy, varnish-like, resembling the (uncooked) white of an egg.

Gland, a group of living cells which makes or "secretes" a special chemical substance, which may either be passed into the general circulation through a canal or duct, or, in the case of the endocrine or "ductless" glands, poured directly into the blood.

gm. (gramme), the unit of weight in the metric system, equivalent to 0.35 oz. avoirdupois.

Graminivorous, grass-eating.

Gustatory, relating to the sense of taste.

Hæmophilia, a hereditary disease of the blood which makes it incapable of clotting, so that even slight injuries involve the risk of the patient's bleeding to death.

Hæmorrhage, bleeding, escape of blood from a blood vessel.

Herbivore, an animal that feeds on grasses and herbage.

Homogeneous, uniform in character, all of the same kind.

Homologous, corresponding, arranged part for part.

Hormone, a chemical substance made by a gland (*q.v.*) and transferred thence to the blood, producing a special activity or effect in some part of the body.

Hypertrophy, over-development, morbid enlargement of part of an organism.

Imbibition, absorption of a liquid by a solid; drinking.

Immunization, an act or process for rendering immune or unlikely to take harm.

Impacted, pressed against, driven in.

Ingest, to introduce food material into the stomach.

Inhibitory, preventive, withholding, restraining.

Innate, inborn.

Innervation, the distribution of nerves to an organ of the body.

Inspiration, breathing in.

Integument, a covering layer of tissue, especially the skin.

Intercostal, occurring between the ribs.

Intravenous, introduced into a vein.

Invaginate, fold in, form a sheath.

Involute, to curve inward, turn under; to

disappear into the surrounding tissues.

Irradiate, to subject to radiation, to direct rays upon.

Kg. (Kilogramme), one thousand grammes (approximately 2.2 lb.).

Km. (Kilometre), one thousand metres (approximately five-eighths of a mile).

Lachrymal, relating to tears or the tear gland.

Lamellæ (*singular*, lamella), thin layers or plates.

Lateral, relating to a side, situated at a side.

Lipoid, fatty, fat-like.

lit. (litre), the unit of capacity in the metric system, equal to 1.76 pints.

m. (metre), the unit of length in the metric system, equivalent to 39.37 inches.

Maturation, ripening; the division of a sex cell by which half the chromosomes of the parent cell pass to each of the two daughter cells.

Mesoderm, the middle germ layer of the germinal disk (p. 19).

Metabolism, the sum-total of the chemical changes which take place in a living body; the building up of new substance (anabolism) and the breaking-down of old (katabolism) considered together.

Metameric, divided into exactly similar segments.

mg. (milligramme), the one-thousandth part of a gramme.

Micron, one thousandth of a millimetre.

Millimicron, one thousandth of a micron; one millionth of a millimetre.

Mitosis, the process of cell division.

mm. (millimetre), the one-thousandth part of a metre.

Molecule, the smallest particle of matter which can lead an independent existence. It is built up of two or more atoms (*q.v.*) which may be of the same or of different elements.

Narcotic, a drug which brings on sleep or drowsiness.

Node, a knot-like swelling.

Nodular, knotty, having nodes.

Nucleolus, a small body of unknown function within the nucleus of a cell.

Nucleus (1) of an atom, the central body, with a positive electrical charge, around which electrons circulate; (2) of a cell, the central part containing the hereditary elements.

Occlusion, blocking up, closing, shutting off.

Olfactory, relating to the sense of smell.

Orientation, change of position to a given direction; relation to the points of the compass.

Osmotic Pressure, the molecular pressure applied to a solution, separated by a semi-permeable membrane from another solution, which controls the diffusion of the solvent of the latter solution into the former.

Oviduct, a tube in the female body by which ova or egg-cells pass from the sex gland (the ovary) to the womb.

Ovum (*plural* ova), the reproductive egg-cell of a female animal which on being fertilized by a male sperm-cell develops into a new individual.

Palpate, feel, examine by touch.

Parenterally, otherwise than by way of the digestive tract (applied to the giving of food, etc.).

Parietal, relating to a wall, especially a wall of an organ or the body.

Parturition, childbirth.

Pathogenic, giving rise to disease.

Peripheral, relating to the external surface or circumference.

Peristalsis, the wave-like movements that convey food through the intestines.

Permeable, porous, allowing fluids to pass through.

Petrous, hard, stony; applied to a part of the temporal bone.

Placoid, plate-shaped.

Plankton, a general name for all small organisms, animal or vegetable, living on or near the surface of the open sea.

Plexus, a network or mass of interwoven nerve-fibres.

Polyhedral, with many sides or faces.

Polyphasal, having a number of successive phases or stages.

Polypoid, resembling a polyp or sea-anemone.

Process, a projection or outgrowth, especially from a bone.

Prophylactic, directed to the prevention of disease, as opposed to the curing of a disease already present.

Prosimians, the more primitive apes.

Protein, one of a class of complex chemical compounds found in all living

matter. Protein molecules, which are very large and varied in composition, are built up from animo acids (see p. 201).

Protoplasm, the complex, jelly-like primary substance from which all living matter is built up.

Punctate, dotted, pitted, pit-shaped.

Purulent, septic, discharging or containing pus.

Ramifying, divided into branches; branching out.

Rectal, relating to the rectum, or final section of the large intestine.

Reduction, replacement of a dislocated joint, of a rupture, or of the portions of a fractured bone.

Renal, relating to the kidneys.

Sac, a structure resembling a pouch or bag.

Saccular, resembling a sac.

Sacculation, a sac-like or cyst-like formation or swelling.

Sanguineous, abounding in blood.

Secretion, a substance formed in and discharged by a gland.

Sepsis, poisoning of the blood, putrefaction and decay caused by small harmful organisms.

Sessile, stationary, permanently attached.

Spastic, spasmodic, subject to spasms.

Spasticity, spasmodic functioning, "going by fits and starts."

Sperm, the reproductive cell of a male animal which by entering an ovum, or female reproductive cell, begins the development of a new individual.

Spicule, a small spike, a tiny sharply pointed fragment.

Spireme, a spiral thread of chromatin in a cell.

Sporadic, breaking out at irregular intervals.

Stellate, radiating, star-shaped.

Suture, the line or seam formed at the junction of the parts of the skull.

Symbiotic, living together—relating to the phenomenon in which two organisms, plant or animal, live in permanent union, each depending for its existence upon the other.

Systole, the contraction of the heart, whereby the blood is impelled outwards; opposed to diastole (*q.v.*).

Tissue, a portion of a living thing made up of cells of one single type adhering to each other.

Tonsillectomy, the surgical removal of the tonsils.

Tonus, tension in a muscle, especially the normal tension when at rest (p. 117).

Transfusion, transferring by pouring; used especially of transferring blood from one animal body to another.

Translucent, allowing light to shine through.

Trapezoid, with four sides of unequal length.

Tubercle, a small projection or swelling.

Vacuole, a tiny globule of clear fluid within the substance of an animal or plant cell.

Vascular, possessing vessels and channels for the circulation of blood, etc.

Venesection, opening or cutting of a vein, especially for blood-letting.

Venous, relating to veins.

Vesicle, a blister, or small bubble.

Villi (singular, villus), tiny outgrowths resembling hairs, particularly in the intestines.

Virilism, masculinity, sexual potency, especially when precocious, premature or in excess.

Virus, the active agent in certain infectious diseases; although probably a living organism, it is too minute to be trapped by a filter or detected with the ordinary optical microscope.

Viscid, thick and sticky, of a treacly consistency.

Index

Page numbers in italics refer to illustrations. Where a reference is to both text and illustration on the same page, the page number is shown in roman type only.

A

Abdomen, musculature, 132-3
— pendulous, 132
Aberration, spherical, 554
Abscess, 187
Accommodation, ocular, 532-4, *539*
Acetic Acid, 236
Acetylcholine, 394, 453
Acidity in digestive tract, 255
Acids, 234-6
Acoustic nerve, 412
Acromegaly, 368
Acrosome, 15
Activity, change of, 116
Acuity, visual, 544-5
Adaptability, human, 317
Adenoids, 214
Adipose tissue, 37, 39, 41
Adrenal cortex, 322, *323*, 365, 394
— gland, *354*, 356-8, 365, 394
— — nicotine and, 342
Adrenalin, 365-7, 394
— and cocaine, 458
— and smoking, 338, 342
— medical uses, 366-7
After-image, *552*, 554-5, 579
After-taste, removing, *304*, *306*
Agassiz, 29
Ageing, 35
— and sex gland, 614-15
Agglutination, 179
Air, 201
— content, of clothing, 353
— dust in, 216-17
— rate of use of, *222*, 225
Airsickness, 511
Albinos, 476
Albinus, 126
Albumin, 307
Albumoses, 236, 258
Alcohol, 4, 334, 338 ff.
— absorption of, 340
— and brain, 338, 340, 425
— and digestion, 260
— and liver, 265
— and musculature, 340
— effects of, 339-41
— habituation, 338-40
— in blood, 338
— when allowable, 342
— whether harmful, 342
Algæ, 6, 357
Alimentary canal, *see* Digestive apparatus
Alkalinity in digestive tract, 255
Alps, cretinism in, 364
Altitude, and blood count, 173, *174*
— effects on man, 205, *206*-7, 208
Alveoli, of breast, *241*
— of cell, 7-8
Ambiculture, 131
Amidopyrine, *429*, 431-3
Amino acids, 201, 233, 236
— and taste, 493
Ammonia, 221, 283, 501
— in tobacco, 336
— in wine, 376
Amœba, 3, 26
Amphibia, blood cells of, 172
— hearing in, 512
— *see also* Batrachians
Amphioxus, 277, 356
Ampullæ, 509
Amylase, 247
Amylopsin, 270
Anæmia, 174
— of brain, *106*
— pernicious, 174
Anæsthesia, 339
— block, *455*, 458, *459*
— general, *456*, 457
— inhalation, *456*, 457
— injection, *456*, 457
— local, 457, *459*
— rectal, *456*, 457
— spinal, 458-9
Analgesics, 431
Angina pectoris, 105, *106*
Angioneurotic œdema, 478
Angle, visual, 545
Angora cats, 470
Ankle, 79
— fractured, 53
Antelope, 492
Anterior chamber of eye, 538
Anterior-horn cells, 401
Anterior lobe of pituitary, 367
Anthrax, 199
Antibodies, 196
Anti-peristaltic movements, 278, 283
Antipyretics, 344
Antitoxins, 196
Ants, 497
Aorta, 140, 148
Aosta Valley, cretinism in, 364
Ape, brain development of, 447, *448*
— cortical areas of, 424, *427*
— posture of, 59
— ribs of, 76
Aperitifs, 340
Apoplexy, 167, 426
Appendicitis, 283
Appendix, vermiform, *28*, 182, 283
Appetite, 332
Appetizers, 301
Apple, chemistry of, 234
— food value of, 305
Applications, hot and cold, 349, *352*
Aristotle, 149, 554
Arm, 79 ff.
— freedom of, 59
— muscles of, 137
— swinging of, *134*, 137
Arrhenius, S., 195
Arsenic, 314
— eaters, 314
Art, primitive, 574
Arterial wall, *159*, *163*
Arteries, 140, 157, 185
— hardening of, 165-7
— rupture of, 167
Arterio-sclerosis, 167
Artery, radial, 149
Artificial lung, 401-2
Arytenoid cartilages, *226*, 227
Ascaris megalocephala, 11
Aschheim-Zondek test, 606
Ascorbic acid, 322
Aspirin, *429*, 431-3
Association, *442-4*, 444
— acts of, 152
— areas, 445
— fibres, 151-2, 444-5
Asthma, 105, *106*, 221-2
Astigmatism, 531, *537*
Asymmetry, blindfold movement and, 127-8
— cause of, 129-30
— facial, 127
— of brain, 130-1
Atavism, 29
Atlas, *69*, 71-2
Atmosphere, adaptation to, 213
— dry and wet, 211
Atmospheric pressure and walking, 136
Atom, 1, 2
Atropine, 265, 541-2
Auditory apparatus, 512 ff.
— canal, *504*, 513, *516*
— cells, 522-3
— centre, 437
— memory centre, 437
— nerves, *504*
— ossicles, *504*, 514, *516*, 517, *519*
Auricle, 142-3, *516*
Auriculo-ventricular node, 150
Avitaminosis, 318, 323
Axial filament, 15, 22, *24*
Axis, *69*, 71-2

B

Bacilli, *see* Bacteria
Bacillus coli, 197
— ureæ, 376
Backbone, 22, 55
— suspension of organs from, 60
— *see also* Spinal column
Bacteria, 5, 6, 191 ff.
— and brain, 416
— intestinal, 282
— lymph and, 189
— nitrogen and, 202-3
Bacteriophage, 195
Balance, 505 ff., *508*
Ball-and-socket joint, *54*, 55
Bandages, plaster, 53
Bartholin's glands, 595
Bat, cortical areas of, *427*
Bathing, effects of, 162
— tub, 479
Baths in antiquity, 467
Batrachians, 71, 82; *see also* Amphibia
Beaks, 59
Beard, 470, 608
Beauty, 62, *64*
Bees and smell, 497
Belching, 254
Bell, electric, 486-7
Belladonna, 333
Benzoic acid, 377
Benzol, *500*
Beri-beri, 321
Bessel, F. W., 383
Biceps, 123, *135*, 137
Bile, 176, 264-6
— acids, 266
— and emotions, 268
— duct, 107, *264*, *267*, 268
Bilirubin, 266
Biliverdin, 176, 266
Binocular vision, *560*, 561
Biogenetic principle, 25
Birds, 59, 60
— equilibrium in, *511*
Birth, and pelvis formation, 78, *70*
— mechanism of, 598
"Black tongue," 328
Bladder, urinary, 374-5, *500*
— inflammation of, 219
Blanching, 104, *106*
Blastula, 18, *20*, 26
Bleeders, 177-8
Blind, and muscle sense, 120
— and touch, 487
— spot, *555*, 557-8, 559
— — psychology of, 559-60
Blindfold movement and asymmetry, 127-8
Blindness, cortical, 434
— memory, 435
— night, 318-20, 552-3
— ocular, 433

Blinking, 530
Blisters, 462
Block anæsthesia, *455*, 458, *459*
Blood, alcohol and, 338
— cells, *168*, 171 ff.
— circulation of, 140, *141*, 157 ff.
— clots, 167, 176
— coagulation of, 176-7, *178*
— composition of, 169
— count, 172-3
— donors, 179
— formation of, 20
— groups, 179
— level, 289
— loss of, 178-9
— menstrual, 603
— pigment, *see* Hæmoglobin
— pressure, 104, 164-5
— — sunlight and, 477
— rate of flow, *156*, 157-60
— temperature, 344
— transfusion, 179, 289
— unchanged, 287-8, *289*
Blood vessels, *21*, 23, 140, *160*
— contraction of, 349
— of ear, *522*
— of intestine, 280
Blubber, 40
Blushing, 104
Body, proportions of, 61 ff.
Boiler crust, 311
Boils, 199
Bone, formation of, 44, *45*, 46
— marrow, *48*, 171, *173*, 174 178-9
— structure, *49*
Bones, *42*, 43 ff.
— and vitamin D, 324
— flexibility of, 50
— forms of, 68
— fractures of, 50-2
— in childhood and age, 50
— number of, 69
— of ear, 517
— strength of, 48
Bouillon, 33, 259, 302
Bouny, 450
Bowel movements, 285
Brachycephaly, 86
Braille alphabet, 486-7
Brain, 35, *409*
— alcohol and, 338, 340, 425
— alterations in, 411
— anæmia of, *106*
— and jaw, proportions, 93
— and race, 447-8
— and sex, 453
— and talent, 450
— asymmetry of, 130-1
— convolutions of, 450
— development, 447
— expansion in man, 59, 60
— fluid, 418-19
— formation, 21-2, *23*
— largest, 450
— lobes of, *418*, 419
— membranes, *see* Cerebral membranes
— of fish, *417*
— position of, in skull, 85
— size and intellect, 449
— stem, 412, *417*
— surface of, 419
— weight, 446-7
Brain cells, 419 ff.
— — counts, 452
Branchial grooves, 27, 28
Bread, 303
Breast, 239-40, *241*
Breastbone, *see* Sternum
Breathing, 204; *see also* Respiration
— exercises, 77, *78*
Brillat-Savarin, 298, 305
Broca's centre, 440
Bromine in food, 314
Bronchial tubes, *220*, 222-3
— catarrh, 222
Broth, meat, 34
Buckwheat disease, 478
Buoyancy of body, *223*, 225
Burns, abdominal, 253
Bursæ, mucous, 56
Butter, 236
Buttermilk, 316
Buttocks, 39
— of Hottentot women, 40

C

Cæcum, *235*, 273-4, 277-8, 280
Cæsarean section, 78
Caffein, 334
Calcium, 4, 8, 43-4, 48-50, *51*, 52, 167, 169
— and sleep, 453
— carbonate, 247
— deposition, and ageing, 615
— in body, 310
— in milk, 311
— in potatoes, 311, *313*
— phosphate, 311, 324, *327*
— regulation of, 359
— sulphate, 377
Callus, 52
Calorie[s], 293, *295*
— requirements, 294, *298*
— and heat loss, 294
Camel, eyelashes of, 529
Camera and eye compared, 527, *529*
Canal, alimentary, *see* Digestive apparatus
— auditory, *504*, 513, *516*
— dentine, 97
— intestinal, 20-1, *272*
— urinary, 371
Canary, weight of brain, 446
Canine teeth, 99, 243, *244*
Canula, 457
Capillaries, 157-8, 181
Capsule, internal, 426, *428*
Car sickness, 210-11
Carbohydrates, 234-5, 281
— calorie value of, 293
Carbon, 139-40
— dioxide, 139-40, 150, *200*, 208-9, 223-5, 283
— monoxide, 209-10
— — in tobacco, 336
Carbuncles, 199
Cardia, 253-4
Cardiac muscles, 108, 144, *147*
— nerves, 150-1
— neurosis, 155
Caries, dental, 100-1
Carnivores, and salt, 309
Carotenase, 318
Carotid plexus, 164, 392
Carotin, 318, *319*
Carp, *411*, *412*
Cartier, Jacques, 322
Cartilage[s], 43-4, 50, 56, 66
— arytenoid, *226*, 227
— costal, 76
Casein, 258, 307
Castration, 611
Cat, intestines of, 273, *274*
— Angora, 470
Cataract, 537
Catarrh, 91
— bronchial, 222
Caterpillar, 425
Cavities, facial, 88
— of skull, 85
— of teeth, *94*, 96
Cavity, oral, *90*
— orbital, 39, *90*
Cell[s], 6 ff., 9
— auditory, 522-3
— blood, *168*, 171 ff.
— brain, 419 ff.
— division of, 9-11, 18-19
— giant, 189
— interstitial, 356
— liver, 263, 265, 379
Cell[s] muscle, *102*, 108
— nucleus of, 7, 8
— olfactory, 421, *423*
— optic, 433
— pyramidal, 421
— sensory, 388
— sex, 14-15, 582 ff.
— shape of, 7
— spinal cord, *399*
— visual, 421, *423*
— wander, *186*, 187, *188*
— white, *see* Leucocytes
Cellulose, 234, 280-1
Centrifugation of milk, *300*
Centriole, 586
Centrosome, 8, 9, 15, 17
Cephalic index, 86
Cerebellum, 407 ff., *409*, *412*, *413*, *415*, *417*
— and locomotion, 411
— diseases of, 411
Cerebral cortex, structure of, 419 ff., *420*
— membranes, 414-15
— — inflammation of, 416
Cerebrospinal fluid, 181, *183*
Cerebrum, 413, 414, *418*, 419 ff.
Cervical fistulæ, 28
— vertebræ, 69-71
Champagne, 340
Change of activity, 116
— of life, 38
Character and obesity, 41
Cheeks, *39*
— muscles of, 125
Cheese, 259
— as food, 305
— moulds in, 197
Cheirotheria, 82
Chest, 76, 77
Chewing, 243
Cheyne, 152
Chiasma, optic, *400*
Child, proportions of, 62, *65*
Childbirth, womb at, *601*
Chin, 93
Chlorine, 221
Chloroform, 339, 457
Chlorophyll, 175, 200, 318, 478
Chlorosis, 174-5
Choked disk, 557
Cholera, 196
Cholesterin, *312*
Cholesterol, 324
Choline, 394
Chordæ tendineæ, 143
Choroid, 538
Chromatin, 8-9, 11, 15, 17
Chromosome[s], 11-12, 25
— maps, 12
— and sex, 13
Chyle, 267
Cigarettes, 337
Cigars, 337
Cilia, nasal, *212*, 214
— of oviducts, 598
Ciliary body, 532
Ciliated groove, *354*, 355
Circulatory system, *30*, 139
Circumcision, 592
Circumvallate papillæ, 491
Cleanliness, 467
Clignot, Chevalier, 251
Climbing, 472
Clitoris, 585, 595
Clivus, 87
Cloaca, 584
Clothing, air content of, 353
— function of, 350
— material for, 353
— women's, 350
Clots, blood, 167, 176
Coagulation, in muscles, 394
— of blood, 176-8, *178*
Coal, iodine in, 360
Coarse foods, 282-3
Cocci, 191

Cochlea, *436*, *510*, *516*, 518, *520-1*, 523
Codeine, *429*, 432
Cod-liver oil, 318, 320-1, 325, 360
Coffee, 306, *330*, 334 ff.
— black and white, 336
— effects of, 334 ff.
— tasting, 494, *495*
Cognac-tasting, 494
Cognition, *432*
Cold, and pain, 458
— feet, effects of, *348*
— perception of, 489
— reflex, 218-19
Colds, 194, 349-50
— and hearing, 516, *518*
— and smell, 501
— protection from, 350
Colic, gall-bladder, *106*, 107
— gall-stone, 268
— renal, *106*, *107*, 374
Collagen, 48-50, *51*
Colon, 274
Colostrum, 308
Colour-blindness, 14, 581
Colour contrast, 579
— vision, 578
— limits, 580
— theories, 580
Colours, complementary, 579
Combustion, 139, *141*, 204, 291
Comminuted fracture, 52
Compasses, and touch sense, 486, *488*
Compounds, chemical, 2
Compresses, warm and cold, *352*
Conception, *582*
Conchæ, nasal, 214, 217-18
Cones of eye, 542, 547 ff., *548*
Connective tissue, *32*, *33*, 34-7
Consciousness, 422, 429
Consonants and vowels, 230-1
Constipation, 107, 285
Contractions, uterine, 599
Contrast, optical, 556
— twilight, 556-7
Convolutions of brain, 450
Cook, Capt., 322
Cooking, 296
Cooling, 343
Copper, 4
— in food, 314
Corium, 462
Cornea, 528, *533*
Coronary vessels, 144
Corpora cavernosa, *590*, 592
Corpus callosum, *417*
— luteum, 601, 606-7
Cortex, adrenal, *see* Adrenal cortex
— cerebral, *see* Cerebral cortex
Cortical areas, 422, *427*
Cough, spasmodic, 217
Coughing, 133, 227
Cow, tongue of, 492
Cowper's glands, 588, *590*
Coxwell, 205
Cramps, heat, 347
Cranial sutures, 87
Cranium, 85
Crawl reflex, 425
Creatin, 377
Cresol, 283
Cretinism, 363-4, *367*
Cribriform plates, 88, *89*
Cricoid cartilage, *226*, 227
Crista galli, 87
Crown of tooth, *94*, *95*
Crying, 530
Crystals and viruses, 195
Curare, 112
Currents, nerve, 400
Curvature of spinal column, 72, 74-5
Cutaneous sensory cells, 370
Cuticle, dental, 98
Cuttlefish, eye of, 527
Cyclones, 211
Cystin, 312
Cystoscope, 372
Cytoplasm, 7, 8, 37

D

Dachshund, 367
Dactyloscopy, 463-5
Dante, 342, 450
Darkness, adaptation to, 552
Darwin, 470
Darwin's point, 513, *515*
"Dead man's float," 225
Deaf mutes, 511-12
— persons, touch sense in, 487
Deafness, memory, 437
Decomposition and smell, 500
Defæcation, 285
Deficiency diseases, 318
Degenerate organs, 28
Degeneration, 67
Deglutition, 247-8
Deiters's nucleus, 407
Deltoid, *135*, 137
Dementia, 426
Democritus, 492
Dental formula, 99
— caries, 100-1
Dentate nucleus, 408
Dentine, *94*, 97
— bacilli and, 100-1
— canal, 97
d'Eon, Chevalier, *609*, 611
Desserts, sweet, 303, *305*
de Torre, Miguel, 336-7
Dextrin, 4, 234, 240, *242*, 247
Diabetes, 271
Diaphragm, 131, 222-3, *228*
Diarrhœa, 285
Diastole, 145
Diet, and teeth, 96
— meat, 316-17
— mixed, 315, 317
— raw food, 315-16
— salt-free, 310
— vegetarian, 316
Digestibility, *260*, 295
Digestion and alcohol, 260
— and fatigue, 297
— individual variations in, 296
Digestive apparatus, *30*, 233 ff., *235*
— gland, *see* Gland, digestive
Digitalis, 357
Diphtheria, 196, 199
— bacillus, 195
— toxin, 195
Dishes, intermediate, 302, *304*
— main, 302, *304*
Disk, choked, 557
— germinal, 18
— intervertebral, 66
— optic, 557
Dislocation, 57
Display, sexual, 607-8
Distance, estimating, 567
Distant vision, 532
Distortion, sense of, 489
Division of cells, 9-11, 18-19
Dizziness, 510
Dog, intestines of, 273
— and smell, 497-8
— fatigue in, *113*
Dolichocephaly, 86
Dolphin, 273
— brain of, *440*, 450
Dorsal eye, *see* Parietal eye
Dragonfly, 26, 424-5
Draughts, fear of, 489
Drosophila, 11, 12
Duality, sexual, 608-9
Duct, bile, 107, *264*, *267*, 268
Ductless glands, *see* Glands, endocrine
Duodenum, *235*, 273
Dura mater, 37, 414, 416
Dust, and nose, 214, 216
— dangers of, 217
Dysentery bacillus, 195

E

Ear, 213, 505 ff.
— and piano compared, 518 ff., *520-1*
— blood vessels of, *522*
— bones of, 517
— external, 513, *515*
— mechanism of, *516*
— middle, 514
— movability of, 513
— muscles, 126, 517
— structure of, *504*
Eardrum, *504*, 514-15, *516*
— perforation of, 515
— rupture of, 515, *517*
Eating, rapid, 297
— reason for, 293
Ebers papyrus, 537
Ectoderm, 18
Ectoplasm, 252
Edison, 35, 64
Education, and brain, 436, 449-50
— and reflexes, 425
Egg, *see* Ovum
— and cell, 6-7
Egg-cell, *see* Ovum
Elbow, *54*, 56
Elbow-joint, 80, 81
Electric bell, 486-7
Electrocardiogram, *152*, 153-4
Electrolytes, 4
Electron microscope, 1-2
Electronic nucleus, 2
Electrons, 1, 2
Elements, 1
Elephant, brain of, 446, *440*
Ellipsoid joint, 55
Emaciation, 39
Emboli, 167
Embryo, among animals, similarity of, *16*, 29
— formation of, 597
— nervous system of, 397
Embryonic recapitulation, 25-6
Emotion, and digestion, 245, 261
— and liver, 268
Emphysema, 222
Emulsion, 236
Enamel of tooth, *94*, 97-8
Encephalitis lethargica, 453
Endocrine glands, *see* Glands, endocrine
Endoderm, 18, 20
End-plates, 110, 112
Energy, potential, 233
Enjoyment and digestion, 261
Enterokinase, 271
Environment and growth, 68
Enzymes, *see* Ferments
Ephedrin, 367
Epidermis, 462, 465
Epididymis, 587, *590*
Epigastrium, 393
Epiglottis, *226*, 227, 248, *250*
Epithelium, 359
Equilibratory apparatus and motion, 510, *512-13*
Equilibrium, 403, 408, *413*, 505 ff., *507*
— metabolic, 331
Erection, 592, *593*
— centre, 594
Ergosterol, 324-5
Erythema, 476
Eskimos, and salt, 309
Ether, 339, 457
Ethyl chloride, 458
Eustachian tube, 514, 515, *516*, *518*
Evaporation, 344, 472
Everest, Mount, 205, *206-7*
Excitement and heartbeat, 151
Excretion, 283-4
Excretory system, *30*
Exercise, need of, 35
Exercises, breathing, 77, *78*
— spinal, for children, 75
Exhaustion, 114

Exophthalmia, 363
Expectancy of life, 616
Extra-pyramidal system, 411
Eye, 527 ff., *541*
— and food, 243
— and vitamin A, 318
— blood vessels of, 542
— colour, 542
— imperfections of, 528, 564
— movements, effects of, 571 ff.
— muscles of, *534*, 564-5
— nerves of, 542-3, *565*, 566
— pigment, 542, *550*, 553
Eyeball, 527
Eyebrows, 529
Eyelashes, 470, 529
Eyelids, 528-9, *534*

F

Face, proportions of, 62
— asymmetry of, 127
— skeleton of, 85, 88 ff.
Fæces, 279, 283-5
Fainting, 105, *106*, 118
Fakirs, 395
Far-sightedness, 535
Fat[s], 235-6
— as fuel, 38
— as insulator, 39-40
— calorie value of, 293
— digestion of, 40
— distribution of, 37-8
— emulsification of, 266
— in men and women, 38
— in stomach, 259
— metabolism of, *286*, 291 ff.
— mobilization of, 40
— pads, 39
— tissue, 37
Fatigue, 113-14
— and toxins, 113, 196
— and digestion, 297
— of eye, 533
— of sense of smell, 501
Fatty acids, 236-7, *286*, 291
Faucal pillars, 248
Fear and seasickness, 511
Feeble-mindedness, 419
Feet, 68
— cold, 218, *219*, *348*, 349
Feminization, 613
Femur, 55, 79
Ferments, 195, 240, 247 ff., 279-80
— combustion, 291-2
Fertilization, 12, 14-15, 17, 598, 603-4
Fever, 346
Fibres, arterial, 157
— association, 151-2, 444-5
— inhibitory, 424-5
— muscle, *102*, 103, 104 ff., 108
Fibrils, *102*, 108-9
— nerve, 380-1
Fibrin, 176-7, *178*
Fibroblasts, 52
Fibula, 79
Field-glasses, 563-4
Filter, urinary, 369 ff.
Finder, telescopic, *547*, 548
Finger, *54*, 55
Fingerprints, 463, *466*, *468*
— formula, 465
Fingertips and touch, 487
Fire, 204
Fish, 413
— brain of, *417*
— scales of, and teeth, 95
— taste in, 491
Fistulæ, cervical, 28
Flat foot, *82*, 83, 84
Fleming, [Sir] Alexander, 198
Floating, 225
Flora, bacterial, of vagina, 597
Flower, how smelt, *503*
Fluids, body, 169-70, *171*
— digestive, 301
Fly, *5*
— eye of, *5*, 6
Focusing, 532
Fœtus, 292
Folds, intestinal, 276-7, *278*
Follicle, 601, 606
Fontanelles, 85-6
Food, and nervous system, 333
— and nose, 243
— classification, 301
— comparative digestibility of, *260*, 295
— preparation of, 296
— raw, 315-16
— requirements, normal, 294
— values, comparative, 295
— wastes, 299
Foot, 82-4,
— arch of, 39, *82*, 83-4
— flat, *82*, 83, 84
Foot and mouth disease, 194-5
Foramen magnum, 87, *89*
Forehead, 88
Foreshortening, 576
Foreskin, 592
Formaldehyde, 234
Formic acid, 236
Fovea centralis, 547, 557
Fowls, sex change in, 612
Fractures, 50-2
— treatment of, 52-3
Freezing, 458
Frequency of tone, 230
Friedman test, 606
Frog, 26
— and light hormone, 477
— heart of, *148*
Frontal lobes, 88, *409*, *418*, 424, 447
Frontal sinus, *90*
Fruit at meals, 304
Fruit-fly, 11
— *see also* Drosophila
Fuel, for human body, 38
— of nerve cells, 380
Fuels, 204
Furuncles, nasal, 416

G

Galen, 458
Gall, *see* Bile
Gall-bladder, *235*, *264*, 267-8
Gall-stones, *266*, 268
Galton, Sir F., 463
Gambetta, 452
Ganglia, 393, 397, 414
Garlic, 360
Gas exchange, 223, *224*
— interchange, man and plant, *200*, 202, 209
Gases, intestinal, 283
Gastrula, *20*, 26
Gastrulation, 26
"Gear mechanism" of ear, 517-18
Gelatine, 33
Genes, 12, 27
Genitals, external, female, 595
— — male, 585 ff.
Germ layers, 18-19, *21*, 24
Germinal disk, 18
Germs, *see* Bacillus *and* Bacteria
Ghosts, seeing, 552
Giants, pituitary, 63, *67*
Gill arches, *354*, 355 ff.
— clefts, 512
— slits, *26*, 27
Gills, *27*
Giraffe, 71
Girdle, pelvic, 79-80
Glaisher, 205
Gland[s], 238-40
— adrenal, *see* Adrenal gland
— and body proportions, 63 ff.
— Bartholin's, 595
— Cowper's, 588, *590*
— digestive, 238-9, 245 ff., *255*, *257*
— endocrine, 239, *354*, 355 ff., 357, *361*
Glands, endocrine and sex gland, *607*
— excretory, 239
— formation, 21, 22, 30
— gastric, 256
— lymph, *see* Lymph glands
— salivary, 244-5
— skin, 238
— sweat, 213, 472
Glans, 592
Glass-swallowing, 250-1
Glasses, 535
Glassy membrane, 240, *241*
Glia cells, 381-2, 421
Globulin, 307
Glottis, 221, *226*, 227
— spasm of, 217
Glucose, 110
Glue, 33
Glycerin, 236
Glycogen, 110, 240, *242*, 271, 292, 596
Gnu, eyelashes of, 529
Goblet cells, 275
Goethe, 35, 64, 91, 454, 467, *471*, 580
Goitre, 363
Golgi apparatus, 380, *381*
— cells, 208
Gonococcus, 197, 476
Gonorrhea, 197, 199
Goose-flesh, 103-4, 467
Gorilla, skull of, *86*
Granules, cell, 8, 9-10, 17
Grape sugar, 292
— molecule, 240
Grasp reflex, 424-5
Gravel, 374
Graves's disease, 362-3, 401
Gravies, 302
Gravitation, 137
Gravity, 505
— centre of, 59
Greenstick fracture, 52
Groove, neural, 20
Growth, 44-5, 64, 582
— and seasons, 66
— duration of, 46, 66
Guinea-pigs, feminized, *612*, 613
Gum, *94*
Gullet, *see* Œsophagus
Gut, primitive, 19, *21*, *22*

H

Haeckel, Ernst, 25
Hæmatoporphyrin, 478
Hæmoglobin, 172, 175, 478
Hæmophilia, 14, 177
Hæmorrhage, brain, 426
Hæmorrhoids, 60
Hair[s], *460*, 467, *474-5*
— and draught, 480
— and hormones, 470
— axillary, 470
— body, 213
— brittle, 312
— care of, 471-2
— colour, 468
— density, 468-9
— duration of, 470
— embryonal, 28, 469-70
— formation, 22, *23*
— gland, 467, 468
— greying of, 468
— growth of, 469
— medulla of, 468
— muscles of, 103, 467-8
— nasal, 214, *215*
— pubic, 470
— root of, *472*
— sensory, and balance, 509, 522
— strength of, 468, *473*
Hand, 39, 81-2
— muscles of, *136*, 137
Hardening of arteries, 165-7
Harelip, *91*, 92
Hasler, Thomas, 63

Hats, effect upon apparent age, 571-3
Haversian system, 48
Head, muscles of, 125
Headache, 416
Hearing, colds and, 516, *518*
— mechanism of, *436*
Heart, 139 ff., *147*, 220
— action of, 145-6
— and jellyfish, *390*, 391
— as automobile, 149
— as engine, 148
— as pump, *138*, 139 ff.
— attacks, 481
— formation of, 23, *25*
— frog's, *148*
— in man and animals, 60
— muscles, *see* Cardiac muscles
— nervous, 154-5
— nervous system of, 391
— number of beats of, 146
— rate of action of, 150
— sound of, 153
— voluntary control of, 152-3, 395
— wall of, 143-4
— work done by, 146
Heat, and taste, 492
— cramps, 347
— perception of, 489
Heatstroke, 347
— dangers of, 348
— prevention of, 348-9
— symptoms of, 349
— treatment of, 348
Hedin, Sven, 128
Heel-bone, *42*, 47
Height, 66
Helix of ear, 513
Helmholtz, 452, 513
Hepatic vein, 263, *264*
Heredity, 12, 13, 14
Hermaphroditism, 609-10
Hernia, 60
— inguinal, *132-3*, 133-4
— strangulated, 134
Herpes zoster, 398
Hinge-joint, 55
Hip-bone, 47
Hip-joint, 55, 136
— tuberculosis of, 80
Hippocrates, 320, 458
Hippuric acid, 377
Histamine, 164
Histidin, 476
Hives, 367
Hogs, white, and smell, 499
Holbein, 129, 309
Holidays, 480
Holmgren, 581
Hormone[s], 40, 271, 292, 355 ff., 604, 605 ff.
— and hair, 470
— and plants, 357, *364*
— corpus luteum, 605, 606-7
— egg-maturation, 605, 606
— female, 605
— follicular, 605, 606
— male, 605
— ovarian, 601-2
— pituitary growth, 605
— pregnancy, 605, 606
Horn, 465
Hors-d'œuvres, 301-2, *303*
Horse, 411
— and man, limbs compared, *80*
— brain of, *449*
Hottentot, brain of, 449
— obesity in, 40
Housemaid's knee, 56
Huggins, Miss, 489
Humerus, 79
Hunger, 331
— centre, 331
Hydraulic pressure in cæcum, 279
Hydrocephalus, 181, 419
Hydrochloric acid, 256, 257-8, 333
Hydrocyanic acid, 336
Hydrogen, 2
— disulphide, 336-7
— ions, and taste, 493
— sulphide, 283
Hydroxide ions and taste, 493
Hymen, 595-6
Hyperopia, 535
Hypertension, 104, *106*, 165
Hyperthyroidism, 40, 362-3
Hypertrichosis, 470
Hypertrophy, cardiac, 167
Hypnosis, 396, 454
Hypophysis, *see* Pituitary
Hypothyroidism, 363

I

Ice Age man, 447
Identification, 442
Idiots, brains of, 451
Illusions, optical, *553-4*, 556, *557*, *568*, 569 ff.
Images, storing of, 443
Impotence, 594-5
Incisors, 99, 243, *244*
Incus, 517
Index, cephalic, 86
Indigo, 377
Indios, *206-7*
Indol, 283
Inertia, intestinal, 107
Infantile paralysis, 401-2, *410*
Influenza, 194
Infraction, 52
Infundibulum, 597, 598, *600*
Infusion, intravenous, 289
Inguinal rings, 133
Inhalation, in smoking, 337
Inhibitions, 425
— alcohol and, 342
Inhibitory fibres, 341
Insomnia, 456
Instincts, 413-14
Insulation, 39
Insulin, *267*, *269*, 271, 292
— treatment, 457
Intellect, and brain size, 449
— and skull shape, 87
Intermaxilla, 91
Interstitial cells, 356
Intestinal canal, 20-1, *272*
— folds, 276-7, *278*
— wall, 275
Intestine, 20, 273 ff.
— after death, 392, *394*
— and earthworm, 391-2, *393*
— and lymph system, 170, *171*
— blood vessels of, 280
— chemistry of, 280
— digestion in, 279, *281*
— large, *235*, 273 ff., *277*
— length of, 273, *274*
— movements of, 107
— nervous system of, 391-2
— small, *235*, 256, 273 ff., *276*
Intonation centre, 442
Intoxication tests, 338
Invagination, 26
Iodine, 40, 359-65, *366*
— and anger, 360
— in body, 360-1
— odourless, 500
Ions, 310, 491
Iris, *533*, 538, *543*
Iron, 4, 8, 176
— and hæmoglobin, 175
— content of foods, 176
Irradiation, *551*, 553-4
Island of brain, *418*, 419
Islands of pancreas, *269*, 271, 292
Ivory, of tooth, *94*, 97

J

Jacobsen, 502
Jaundice, *266*, 268, 329
Java man, 447, *448*
Jaw, and brain, proportions of 93
— lower, 92, *93*
— muscles of, 125
— use of, by animals, 59, 92
Jeffries, Benjamin, 581
Jelly of Wharton, 32
Jellyfish, and heart, *390*, 391
— equilibrium in, 505, *506*
Joint cavity, 54
Joints, 45, 53-4
— false, 53
— origin of, *53*
— types of, 54-5
— vertebral, 71
Judgments and vision, 578
Juice, pancreatic, 40, 270-1

K

Kant, 454
Kefir, 242
Keller, Helen, 489
Kestrel, eye of, 527
Kidney[s], 35, 288, 369 ff., *369*, *373*, *375*
— and salt, 310
— and tonsillitis, 372
— contracted, 166, 372
— disease in, 372-3
— floating, 60, 369
— middle, *354*
Kiss, nose, 503
Kissing, racial attitude to, 503
Knee-bend, 81
Knee-cap, *see* Patella
Knee-joint, *55*, 80-1
Knock-out, 164

L

Labia majora, 595
— minora, 595
Labour pains, 108
Labyrinth, 90-1
Lachnanthes, 499
Lactalbumin, 307
Lacteals, 170
Lactic acid, 113, 596
Lactification, 267
Lactoflavin, 328
Lactoglobulin, 307
Lamellar corpuscles, 489
Lamina cribrosa, 88
Lamprey, 277
Language centre, 440
Languages, learning, 437
Lanugo, 28
Laryngitis, 219
Larynx, 45, 213, 221, *226*, 227 ff. 230
— food in, 248
Lead poisoning, 372
Learning, 152, *438-9*, 442
Leather, 462
Lecithin, 311
Left-handedness, 129
Legs, 68, 79 ff.
— asymmetry of, 127
— growth of, 64
Leguminous plants, 202-3
Lemons, 298, 318
Lenin, brain of, 452
Lens, *526*, 531 ff.
— elasticity of, 532
Leprosy, 404
Lessing, 337
Leucine, 377
Leucocytes, 171, *173*, 176, *177*, 185-7
Life, origin of, 3
— conservation, prospects of, 617
Lift, motion in, 509, *513*
Light, and shade, 576
— effects of, on skin, 476 ff.
— hormone, 477-8
— sickness, 478
— speed of reaction to, 385

Light starvation, 481
— wave-lengths, 578
— when harmful, 478
Limbs, formation of, 23
Lipase, 270
Lips, and speech, 231
— and touch, 486
Liqueurs, 306, 340
Liver, 21, 40, 175, *235*, 263 ff., 292
— and alcohol, 265
— and emotions, 268
— and fluids, 288
— cells of, 263, 265, 379
— cones, *262*, 263
— passive congestion of, 265
— structure of, 263-4
— wounds, 263
Llama, 172
Lobar pneumonia, 197
Lobe, parietal, *418*
Lobes, frontal, 88, *409*, *418*, 424, 447
— occipital, *418*
Lobster, equilibrium of, 505-6
Lumbar puncture, 181
Lumen, 20, 256
Lung, artificial, 401-2
Lungs, 60, 172, *220*, 221 ff.
— inflammation of, 219
Lupus, 310
Luschan, Felix von, 63, *67*
Lymph, 170-1, 180 ff.
— cochlear, *504*
— glands, 171, 183, *184*, 189
— nodes, 182, *184*
— of ear, 507 ff., 524
— system, *30*
— vessels, *180*, 181-2, *184*
— — of intestine, 280

M

M. and B. 693, 197
Macallum, 169
Machnow, 63, *67*
Magnesium, 169, 175
Male, bodily development of, 608
Malformations, 28
Malleus, 517
Malt sugar, 240, *242*, 247
Mammary gland, *see* Breast
Mandible, 92
Manganese, 4
— in food, 314
Maoris, nose kiss among, 503
Marathon race, 340
Marrow, *see* Bone-marrow
Masculinization, 613
Massage, 35, 115, 478-9
Mastoid cavity, 514
Match, lighting of, 291
Materials, light and dark, 350
Maturation, 12
Maxilla, 91
Maxillary sinus, *90*, 91
Measles, 194, 196
Meat broth, 34,
— diet, 316-17
— extract, *see* Bouillon
— toughness of, 34
Meconium, 284, 308, 470
Mediums and swallowing, 252
Medulla oblongata, 162, 164, 404-7, *408-9*, 417
Medusa, 391, 505
Megalomania, 426
Meibomian follicles, 529
Melanin, 476
Membrane, nuclear, 9-11
— of brain, *see* Cerebral membranes
Memory blindness, 435
— centre, auditory, 437
— optical, 434
— wizards, 437
Meninges, 414, 418-19
Meningitis, 199, 416
Meningococci, 197
Menopause, 612, 613
Menstruation, 603
Menu, 301-2
Mercaptan, 501
Mercury vapour lamps, 325
Mesentery, 274, *277*
Mesocephaly, 86
Mesoderm, 19
Mesonephros, *354*
Metabolic centres, 289
Metabolism, 287 ff.
— fat, *286*, 291-2
— protein, 292
— sugar, 292
— water, 287, *289*
Methane, 283
Micrococcus ureæ, 376
Microscope, 4-6
— electron, 1-2
Middle ear, inflammation of, 514
Migraine, 160, 217
Milk, 6, 236, 240
— as food for adults, 308
— as food for children, 306-7
— bacilli and, 191
— calcium in, 311
— centrifugation of, *300*
— digestion of, 258
— duct, 239
— human and cow's, 307
— products, *300*
— salts in, 307-8
— teeth, 98, *100*
Mimic musculature, 126-7
Minerals in food, 309 ff.
Miner's beat elbow, 56
Mitosis, 9, 11, 12-13
Mitral valve, 142
Möbius, *449*
Molars, 98, 99, 243, *244*
Molecules, 2, 233-4, *238*, 240
Mommsen, 451
Monthly period, 602, *603*
Moorhen, eye of, 527
Morphine, 333, *429*, 431-3
— and eye, 541
Morula, 18, 26
Mosaic disease, 194-5
Mosquito, 26
Motion, and equilibratory apparatus, 510, *512-13*
Motor and muscle compared, 109-10, *111*
— centre, 113, 424, 426, *428*
— tracts, 400, *405*
Mouches volantes, 537, *540*
Moulds, *5*, 6, 197
— in cheese, 197
Mountain sickness, 208
Mouth, digestion in, *242*, 243 ff.
Movement, voluntary and involuntary, 113
Mucin, 275
Mucous tissue, 32
Mucous membranes, 275
— and alcohol, 340
— and vitamin A, 320
— olfactory, 498
— uterine, 602
Mucus, nasal, 88, 216, 217
— vaginal, 596
Muscle[s], as fluid reservoir, 288
— cells, *102*, 108
— contraction, 394
— flexor and extensor, 123
— number of, 108
— oxygen and, 110
— sense, 119-20
— — blind and, 120
— shapes of, 108
— smooth, *106*, 107-8
— stomach, 253
— striated, 108, *109*
— structure, *102*
Musculature, 102 ff.
— alcohol and, 340
— formation of, 20, *21*, *30*
— intestinal, 275-6
Musculature of abdomen, 132-3
— of arm, 137
— of cheek, 125
— of ear, 126, 517
— of eye, *531*, 594-5
— of hair, 103
— of hand, *136*, 137
— of head, 125
— of heart, 108, 144, *147*
— of oesophagus, 105-7
— of trunk, *130*
Musk, animal, 501-2, 502
— deer, 172
Myasthenia gravis, 364
Myelin, 381
Myopia, 535, 541
Myxœdema, 363

N

Nails, brittle, 312
Napoleon, 64
Narcotic[s], 339, *420*, 431
— alcohol as, 339
Nasal cavity, 213
— chambers, *90*
— cilia, *212*, 214
— conchæ, 214, 217-18
— maladies, 60
— turbinates, *216*, 497-8
Near-sightedness, 535
Near vision, 532
Neck, effects of blow on, 164
— in man, 60
— — clefts, 28
— muscles of, 125-6
— of giraffe, *71*
— of tooth, *94*, 95
Needle, injection, 457
Nerve[s], 398-400
— acoustic, 412
— and muscles, 112
— auditory, *504*
— cardiac, 150-1
— cells, 379, *381*
— currents, 393
— fibre, 380, *381*
— impulse, speed of, 382
— mixed, 399
— of eye, 542-3, *565*, 566
— of tooth, 96-7
— optic, 412, 433, 542
— vagus, 151, *378*
— vasomotor, *105*, 191-2
Nervous system, *30*, 379 ff.
— abdominal, 391 ff.
— and endocrine glands, 357
— and food, 333
— central, 397 ff.
— diseases, 398
— in embryo, 397
— sunlight and, 477
— sympathetic, 392 ff.
Neuroglia, 381
Neuroma, 431
Neurons, *386*, 387-9
— connecting, 388, 389
— cortical, 388, 389
— internuncial, 389
— motor, 388-9
— segmentary, 390
— sensory, 387-8
— types of, 387-8
Neurosis, 217
— cardiac, 153
— vascular, 160
Newton, 580
Nicotine, 336, 337, *341*, 342
— effect of, on eye, 541
— on system, 338
Nicotinic acid, 321, 328
Night blindness, 318-20, 552-3
Nissl granules, 380
Nitrates, 202-3
Nitrogen, 201 ff.
— and bacteria, 202-3
— cycle, 202-3
Nodes, lymph, *see* Lymph nodes

Norton, Col., 205, *206-7*, 208
Nose, 212 ff.
— aesthetic value of, 503
— and food, 243
— dog's and man's, compared, 499
— dry, and smell, 499
— kiss, 503
Nucleolinus, 8
Nucleolus, 8
Nucleoprotein, 380
Nucleus, Deiters's, 407
— dentate, 408
— electronic, 2
— of cell, 7, 8
— of nerve cell, 380
Nutrition and size, 67
Nutritional losses, 298-9
— values, 295
Nyctalopia, 553

O

Obesity, 38, 40
— and character, 41
Occipital lobe, *418*
Occupational tests, 385-7
Ocular fluid, 528
Odour-carriers, 501
Odours, and food, 245
— burnt, 501
— ethereal, 501
— flowery, 501
— kinds of, *500*, 501
— putrescent, 501
— reaction to, speed of, 385
— spicy, 501
— tenacity of, 502
Œdema, angioneurotic, 478
Œsophagus, 20, 250-1
— muscles of, 105-7
— spasm of, *106*
Oils, 233, 236
— volatile, and smell, 499
Olfactory cells, 421, *423*
— cortex, 421, *423*
— lobe, *400*
— sense, training of, 502
— — *see also* Smell
— stimuli, 497
— system, 88
Olivary body, 407
Olive, 407
Olympic games, 340
Operations, intestinal, 395
Opium, *429*, 431-3
Opsonins, 189
Optic cells, 433
— chiasma, *409*
— disk, 557
— nerve, 412, 433, 542
Optical illusions, *553-4*, 556, *557*, *568*, 569 ff.
— memory, 434
Oral cavity, *90*
Orang-outang, brain of, 451
Orbital cavity, 39, *90*
Orbits, electronic, 2
Organ systems, *30*, 31-2
Organism, 3
Osmophores, 501
Osmotic pressure, 4
Ossicles, auditory, *504*, 514, *516*, 517, *519*
Ossification, 43-4
Osteoblasts, 45
Osteoclasts, 45
Ovaries, 38, 585, *597*, 600, *602*
Overtones, 229
Oviduct, *14*, *582*, 585, *597*, 598
Ovum, 12, 17 ff., 582 ff.
Ox, eye of, 531
Oxalic acid, 377
Oxidation, 204, 291-2, 293, 343
Oxygen, 139-40, *200*, 204 ff., 223-5
— and muscles, 110
— consumption, 41
— odourlessness of, 500
Ozone, odour of, 500

P

Pain, and sympathetic system, 395
— causes of, 483-4
— phantom, 431
— sensation, speed of, 383
— spots, 484
— value of, 403
Palate, 91, 248
— arched, 214
Palatine bone, 91
Paling, *see* Blanching
Palmitic acid, 236
Pancreas, 21, 40, *267*, *269*, 270 ff.
— islands of, *269*, 271, 292, *354*, 355-6
Pancreatic amylase, 270
— juice, 40, 270-1
Papillæ, 463
— circumvallate, 491
— of tongue, 49, *244*
Papillary muscles, 143
Para-casein, 258
Paralysis, agitans, 412
— by curare, 112
— infantile, 401-2
— pupillary, 542
Paramecium, 195
Parasites, 6
Parasympathetic cells, 393
Parathormone, 359
Parathyroids, *354*, 356, 359
Paresis, 425
Parietal eye, *354*, 355
— lobe, *418*
Parotid glands, 245, 246
Patella, 81
Patellar reflex, 398-9, *402*
Pavlov, 40
Pellagra, 328
Pellagra-preventive factor, 328
Pelvic bowl, 76
— girdle, 79-80
— ligaments, *33*
Pelvis, 68, 77-8
— renal, 372
Penicilli, 185
Penicillin, 197-9
Penicillium album, **197**
— glaucum, 197
— notatum, *190*, 198
Penis, 585, 592
Peppermint, 501
Pepsin, 256-8, 266
Peptones, 236, 258
Perception, primary, 412-13
Perforation of eardrum, 515
Pericardium, 144-5, *146*
Perichondrium, 54, 56
Period, monthly, 602, *603*
Periosteum, dental, *see* Root-sheath
Peripheral phenomenon, 552
Peristaltic waves, 251, 254, 275, 276, 278
Peritoneum, 32, *34*, 145, 274
Pernicious anæmia, 174
Personal equation, 383
Perspective, 574
Perspiration, *see* Sweat
Petechiæ, 322
Petrous bone, 87, *89*
Phagocytes, 185, 189, *272*, 477
Phenol, 283, 312
Phosphorus, in body, 311
— in milk, 308, 311
Photophobia, 476
Physiognomy, 127
Physostigmin, 395
Pia mater, 414, *416*
Piano and ear compared, 518 ff., *520-1*
Pig, 273, 492
Pigment, albinos and, 476
— and sense of smell, 498-9
— blood, *see* Hæmoglobin
— layer, of eye, 538
— of eye, 542, *550*, 553
— of skin, 366
Pigtail, strength of, 468
Pineal gland, *354*, 355, 357-9, *417*
Pitch of sound, 229
Pithecanthropus, 447, *448*
Pituitary, anterior lobe of, 367
— chiasma, *409*
— giants, 63, *67*
— gland, 63-4, 87, 355, *357*, 367, *368*, *417*
Pituitrin, 368
Pivot-joint, 55
Plague, 196
Plankton, 203
Plantar reflex, 424
Plants, nutrition of, 233
Platelets, blood, 176, *177*
Plato, 342, 431, 584
Pleura, 145, 222
Plexus, carotid, 164, 392
— solar, 164, 392
Pneumococcus, 197
Pneumonia, 197, 198, 199, 248, 250
— lobar, 197
Poggendorf phenomenon, 573
Poisons, 333
— and kidneys, 372
— effects of, 164
Poliomyelitis, 194
Polypeptides, taste of, 493
Ponies, Shetland, 67
Porphyrin, 478
Portal vein, 263, *264*
Posterior lobe, of pituitary, 368
Posture, and spinal curvature, 75
— erect, of man, 59
— — disadvantages, 60
— of ape, 59
Potassium, 169
— cyanide, 312
— — in foods, 313
— thiocyanite, 312
Potato, 303
— calcium in, 311, *313*
— nutritional value of, 295
— vitamin C content, 324
Pot-belly, 325
P-P factor, 328
Precentral convolution, 426
Pregnancy, 597, *600-1*
— extra-uterine, 599
— intra-abdominal, 599
— tests, 606
— tubal, 600
Premolars, 99, 243
Presbyopia, 535
Pressure, lines of, 46
— atmospheric, and walking, 136
— osmotic, 4
— sense of, 489
Primitive art, 574
Primum oriens, 143
Printing, 405
Prisms, 563-4
Prolapse of uterus, 60
Proportions of body, 61 ff.
— of child, 62-3, *65*
— facial, 62
Prostate, 585, 588, *590*
Protein[s], 4, 201, 233, 234, 236
— and raw foods, 315
— energy loss for, 290
— human, formation of, 265
— metabolism, 292
— — and fever, 347
— minimum, 294
— molecule, digestion of, 258
— quality, 297
Protoplasm, 3, 4, 7, 110
Pseudarthrosis, 53
Psittacosis, 194
Psychotechnics, 383
Ptosis of stomach, 60
Ptyalin, *242*, 247
Puberty, 64
Puerperal fever, 197, 199
Pulp, of tooth, *91*, 96
Pulse, 148-9
— feeling, *151*

Pulse rate, *154*
Punctum saliens, 149
Pupil, 104, 541 ff.
 — contraction of, *106*, 540
Pupillary paralysis, 542
Purkinje cells, 408
Purple, visual, 552
Pus, 187
Putrefaction, 257
 — in large intestine, 282-3
Pyloric sphincter, 255
Pylorus, 253-6
Pyramidal cells, 421
 — tracts, 400
Pyridine in tobacco, 336

Q

Quadruped, man as, 137
Quinine, *429*, 431-3

R

Rabbits, and buckwheat, 478
 — and smell, 497
Rabies, 194
Radial artery, 149
Radiation, and senses, 482
 — cell and, 8
 — skin and, 473
 — *see also* Sunlight
Radius, 79, 81
Rats, rejuvenation in, 614, *615*
Raw food, 315-6
Reaction, stimulus and, 388-9
 — speed of, 383-5
Recapitulation, 25-6
Receptor cells, 379
Recognition, 442-3
Rectum, 274, 285
Red nucleus, 117
Redness of skin, 476
Reducing, 40
Reflection, 445
Reflex, 217, 389, *402*
 — arc, 398
 — patellar, 398-9, *402*
Rejuvenation, 614-15
Relaxation, muscular, 117
Rennin, 256, 258
Resonance, 483
Resonating spaces, 229
Resonators, 483
Respiration, 222-3
 — mechanism of, *224*
Respiratory apparatus, 213
 — centre, 213, 225
 — chambers, 221, 223
Rest, 115-16
 — of heart, 146
 — periods, in work, 385
Reticular substance, 405
Retina, 538, 542 ff., *544*, *546*
 — bipartite nature of, 550
 — cortical, 433
Rhinoceros, white, 409
Rhomboid fossa, 404-5
Riboflavin, 321, 328
Ribs, 23, 68, 76-7
 — of ape, 76
Rice, polished, 321
Rickets, 50, 318, 324-5
 — treatment, *326*, 327
Right-handedness, 127
Rigor mortis, 114
Rods of eye, 542, 547 ff., *548*
Root nodules, 202-3
Root, of tooth, *94*, 95, 96
 — canal, *94*, 96
 — sheath, *94*, 95
Rotary joint, 55
Rowing and chest development, 77
Rubber clothing, 352
Ruffling of hair, 103-4
Rufus of Ephesus, 346
Rupture, 60
 — of eardrum, 515, *517*

S

Sacrum, 69
Saddle-shaped joint, 55
Salads, 303, *305*
Saliva, 245-6, 287
 — composition of, 246-7
Salivary glands, 244-5
Salivation, mechanism of, *249*
Salmon, 411
Salt, 2
 — as wages, 309
 — carnivores and, 309
 — god, 309
 — in blood, 169
 — in food, 309-10
 — iodized, 365
Salt-free diet, effects of, 310
Salts, in milk, 307, *308*
 — in protoplasm, 4
Salvarsan, 314
Sauerwein, 452
Savoy, cretinism in, 364
Scales, fish, 95, *96*
Scapula, 137
Scarlet fever, 196-7
Scars, 166
Schopenhauer, 431, 454
Scoliosis, 74-5
Scopolamine, 542
Screw membrane, 468, *475*
Scrotum, 585-6
Scurvy, 298, 318
 — infantile, 322-3
 — sea, 322
Sea, as source of life, 169
Sea-water, 309
Seal, 273
Séances, 252
Seasickness, 510-11
 — remedies, 511
Sebaceous glands, 22, *23*, 103
 — of eye, 529
Second wind, 114
Secretin, 259-60
Secretion, internal, 355, *356*
Segmentation, rhythmic, 275
Segments of nervous system, 398
Sella turcica, 87, *89*
Semen, 587, 594
 — ejaculation of, 593
Semicircular canals, 508-10, *516*
Semi-lunar valves, 143
Seminal ducts, 585-7
 — fluid, 587
 — vesicles, *590*
 — — secretion of, 587-8
Seminiferous tubules, 586
Sense organs, kinds of, 483, *484*
Sensitization, 478
Sensory area, 426 ff.
 — buds, 491
 — cells, 379, 388
 — fibres, 119-20
 — organs, *30*
 — tracts, 403, *405*
Serotherapy, 457
Serum, therapeutic, 196
Sex, and brain, 453
 — and chromosomes, 13-14
 — canal, 584
 — cells, 14-15, 582 ff.
 — characteristics, secondary, 607-8
 — determination, 13-14
 — differences, 7, 8
 — dual nature of, 608-9
 — glands, 63, 64-6, 357, *587*
 — — and age, 605, 614, 615
 — — hormones of, 605 ff.
 — linkage, 14
 — organs, general plan, 584
 — — female, 595 ff., *596-9*
 — — male, *591*
 — transformation, 612-13
 — uncertainty, 610
Sharks, teeth of, 98
Sheep, 273, 411

Shin-bone, 50
Shingles, 398, *399*
Shivering, *105*, 343
Shock, 162-4
Shoulder, *54*, 55
 — girdle, 79-80
Sight, mechanism of, *430*, *432*, *540*, *541*
 — *see also* Vision
Sigmoid flexure, 274
Silence, zone of, 490
Silica dust, 217
Silver bromide, 387
 — chromate, 387
Sino-auricular node, 150
Sinus, frontal, *90*
Sinuses of brain, 416, *417*
Sinusitis, 416
Skatol, 283
Skeletal system, *30*
Skeleton, 43, *70*
 — architecture of, *68*
 — formation, *20*, *22*, *24*
 — male and female, *77*
Skin, 22, *100*, 461 ff.
 — acid coat of, 473
 — and massage, 478-9
 — area, 461
 — care of, 35
 — complexity of, *461*
 — greasy coat of, 470, *476*
 — pigment, 366
 — radiation and, 475 ff.
 — redness of, 476
 — regeneration of, *466*
 — ridges of, 462-3, *464*
 — structure, 462
 — weight of, 461
Skull, 68, *80*
 — at birth, 85
 — base of, 87
 — deformation, 86
 — development, *84*
 — joint of, 56
 — strength of, 50
 — structure, 84 ff.
 — types, *86*
Sleep, amount needed, 454
 — brain and body, 453-4
 — centre, 453
Sleeplessness, 456
Sleepy sickness, 453
Smallpox, 194, 196
 — and light, 478
Smegma, 592
Smell, 497 ff.
 — a mixed sensation, 501
 — and taste, 494
 — bees and, 497
 — chemistry of, 499-501
 — colds and, 501
 — diagnosis by, 502
 — fatigue, 501
 — physics of, 499
Smoking, 336
 — and adrenalin, 338, 342
Snail, 425
Sniffing, 499
Soap[s], 233, 311
 — stools, 40
 — use of, 467, *469*
Sodium, 169
Softening of water, 311
Solar plexus, 164, 392
Solidity and distance, 563
Solution, 234
 — pressure, 4
Somnambulism, 454
Sound, how formed, 228
 — memory, 440
 — speed of reaction to, 385
 — waves, 228
Soups, 302, *303*
Space, dimensions of, 509
 — perception, 574
Spasm, *106*
Specialization, lack of, in man, 317
Spectacles, 535, 536

Spectrum, 578
Speech, 231
— and jaws, 93
— centre[s], 131, 440-1
— development of, 60
— learning, 442
Sperm[s], 12, 14-15, 17, 582, *586*
— canal, *586*
— cell, 379, 582, 586 ff.
Spermatic cord, *590*
Spermin, 587
Spherical aberration, 554
Spheroid bone, 87
Sphincter of iris, 538
— pyloric, 255
Spinal anæsthesia, 458-9
— exercises, 75
Spinal column, 72, *74*; *see also* Backbone
— relation to body, 61
Spinal cord, *30*, 37, 397-8, *401*, *404*
— anæsthesia of, 458
— cells of, 399
— tracts of, 399-400
Spine, curvature of, 72, 74-5
Spireme, 11
Spirilli, 191
Spleen, 183-5, *184*
Splinter, *186*, 187
Sprain, 56-7
Spring sickness, 323
Sprue, 174
Standing still, 134-5
Stapes, 517, 524
Staphylococci, 198
Starch, 233-4, 240, *242*
Stars and brain-cells, 422, *424*
Starvation, time required for, 333
Statocysts, 505
Stature, average, 67
Stearic acid, 236
Steatopygy, 40, *41*
Steinach, *612*, 614
Sterility, 599
Sternum, 76
Stimulants, 301, 333, 433
Stimulation, alcoholic, 340
Stimulus, and reaction, 388-9
— images, 405 ff.
Stomach, 20, *22*, *235*, 253 ff., *258*
— movements of, 254-5
Stones in kidneys and bladder, 320, 374
Stools, *see* Fæces
Stratosphere, *206-7*
Streptococci, 193, 198
— hæmolytic, 197
Streptomycin, 199
Stroke, apoplectic, 167
Strychnine poisoning, 403
Sublingual fold, *28*
— glands, 245, *247*
Submaxillary glands, 245
Successive contrast, 556
Sugar[s], 38, 233, 234-5
— in protoplasm, 4
— metabolism, 292
Sulphadiazine, 197
Sulphanilamide, 197
Sulphapyridine, 197
Sulphathiazole, 197
Sulphur, in body, 311-12
— metabolism of, 312, *314*
— odourless, 500
Sulphuretted hydrogen, *see* Hydrogen sulphide
Sulphuric acid, 312
Sun-baths, 479, *480*
Sunburn, 324
— and skin, 462, 476
Sunlight, and bacteria, 476
— effects on skin, 476 ff.
— nervous system and, 477
— starvation, 325
Sunstroke, *346*, 347
— prevention, 347
Suppuration, 187
— of middle ear, 416
Sutures, cranial, 87
Swallowing, 248, *250*, 407
— and speaking, 248-9
— upside-down, 251
Sweat, 344, 472
— glands, 213, 472
— — formation of, 22, *23*
Sweets, 303
Swine fever, 194
Switzerland, iodine in, 359, 360
Sword-swallowing, 251
Symmetry, real and apparent, 571
Sympathetic and vagus system, relations between, *396*
— cells, 393
— nerve, 151
— system, 113
— — and sensation, 395
Synapses, 387
Synovial fluid, 54, 56
Syringomyelia, 404, *410*
Systole, 145
Szilagyi, 452

T

T cells, 408
Tabes, 403, *410*, 542
Tactile corpuscles, 485, *486*
— ridges, 463
— sense, achievements of, 487
— — differentiation by, 486-7
— — *see also* Touch
Taguchi, 450
Tahra Bey, 153
Tail, rudimentary, 29
Talent, and brain, 450
— olfactory, 502
Tanning, 476
Tarsus, 83
Tartar, dental, 246-7
Taste, and smell, 494
— buds, 231, 491, 492
— changes of, 493
— chemistry of, 493
— constituents of, 493-4
— experiments in, 496
— physics of, 492
— pits, *492*
— zones, *490*, 493
Taurin, 312
Taurochol, 312
Tea, 336
Tear[s], 530
— canals, 530, *534*
— ducts, 530
— gland, 218, 530, *534*, *535*
— sac, *534*
Tectorial membrane, 523
Teeth, *94*, 95 ff.
— and food, 243
— canine, 99, 243, *244*
— diet and, 96
— diseases of, 100-1
— irregular, 101
— replacement of, 98
— structure of, 95-6
— varieties of, 98-9
— wisdom, 100
Telescope and eye, *547*, 548
Television, 405, 433
Temperament and iodine, 362
Temperature, body, 204, 343 ff.
— centre, 543
— corpuscles, 213
— curve, 345-6
— daily variation of, 345
— lowering, by drugs, 433
— measuring, 345
— of blood, 344
— of body fluids, 169
Temporal bone, 506
— cortex, *436*
— lobe, *409*, *418*
Tendon[s], *119*, 122
— of heart, *145*
— sheaths, *119*, 122
Tension, muscular, 104
Testicles, 585-6, *590*
Tests, occupational, 385-7
Tetanus, 199, 402
— bacillus, 196
— physiological, 116
Tetany, 359
Thalami, optic, 434
Thales, 309
Thermometer, 345
Thick-set type, 64
Thigh-bone, *42*, 48, 55, 68, 136
Thirst, 331
— centre, 331
— quenchers, 301
Thoracic duct, 171, 182
Thorax, 68, 75-6
Thought, speed of, 382
Throat, dry, 331
— sore, 199, 219
Thrombi, 167
Thrombocytes, *see* Platelets, blood
Thrust-lines, 46
Thumb, opposition of, 82
Thymus, 63-4, *354*, 356-7, 359, *362*
Thyroid, 40, 63, *354*, 356, 359-63
— cartilage, *226*, 227
— colloid of, 362
Thyroxin, 362
Tibia, 79
Tickling sensation, 484
Timbre, 229
Time and human body, 114-15
Tissandier, 205
Tissues, 31
Tobacco, 306, 336 ff.
— heavy and mild, 337
Tolstoy, 35, 128
Tone, muscle, 116-17
Tones, colour, 579
Tongue, 28, *490*, 491-3
— and food, 243-4
— and speech, *230*, 231
— black, 328
— taste buds in, 491
— tip of, *486*
Tonsillitis, and kidneys, 372
Tonsils, 182, *354*
— pharyngeal, 213
Tonus, abnormal, *115*, 118-19
— decreased, *116*, 117-18
— muscular, 104, 125, 161
— — sunlight and, 477
— of blood vessels, 162
— of stomach, 254
Tooth, pulp of, *94*, 96
— wall of, 97
Toothache, 97
Touch, 463 ff.
— blind and, 487
— fingertips and, 487
— geniuses, 487
— sense, 484 ff.
Townsend, Col., 152-3
Toxic substances, liver and, 265
Toxins, 95-6
— fatigue, 113, 196
Trachea, *see* Windpipe
Training, muscular, 121-2
— of reflexes, 425
— of sympathetic system, 395
Transfusion, blood, 179, 289
Triceps, 123
Tricuspid valve, 142
Trigeminal nerve, 397
Trumpet, 229
Trunk, muscles of, *130*, 131-2
Truss, 134
Trypsin, 270
Tub bathing, 479
Tube[s], bronchial, *220*, 222-3
— Eustachian, 514, 515, *516*, *518*
— integumentary, 20, *21*
— intestinal, 20, 23
— neural, 20, *21*, 22
Tubercle bacillus, 194, 477
Tuberculosis, 199
Tubules, collecting, 372, *374-5*
Turbinates, nasal, 497-8, *216*
Turkish saddle, 87
Turkomans, 312

Twilight contrast, 556-7
Twitch, muscular, 116
Tympanic membrane, 514
Tyndall, 502
Typhoid, 196
— bacillus, 194
Tyrosin, 476

U

Ugolino, Count, 333
Ulcers, 165
— intestinal, 179
Ulna, 79, 81
Ultra-violet lamps, 327
— rays, 324-5, 327, 481
Umbilical cord, 32
Understanding, 442
Ungulates, 487
Uranium, 2
Urea, 376
— in sweat, 473
Ureter, 107, 369, 372
Urethra, *375*, 587, 588, *590*, 593
Urethral orifice, 595
Uric acid, 377
Urinary bladder, 374-5, *590*
— canal, 371
— filter, 369
Urine, 376, *377*
— bacteria in, 376-7
— colour of, 376
— preparation of, 371-2
— testing, 372
Urinometer, 376
Urobilin, 376
Urochrome, 376
Uterine contractions, 599
Uterus, 585, 596 ff., *see also* Womb
— muscles of, 108
— prolapse of, 60
Uvula, 248, *250*, 515

V

Vacuoles, protein, 8
Vagina, *582*, 585, 596-7
Vagus cells, 393
— nerve, 151, *378*, 393
Valves of heart, 141, *142*
Van Hoorne, 158
Varicose veins, 60, 161
Vasa vasorum, 157
Vascular neurosis, 160
— spasm, *106*
Vasomotor nerves, 161-2, *165*
Vegetables at meals, 303
Vegetarian diet, 316
— peoples, intestines of, 273
Vein, wall of, *159*
Veins, 140, 161
Ventricle, 141-2, *143*
Vermiform appendix, *see* Appendix
Vertebræ, 47, *54*, 69 ff.
— formation of, 22, *24*
— groups of, 69
Vertebral column, *21*, 22, 69 ff.
Vertigo, 510
Vibrios, 191
Villi, 21, *22*
— intestinal, *272*, *278*, 280, *282*
Violin, 229
Viruses, 2, 193-5
Viscera, pain sensations of, 395
Vision, 433 ff.
— binocular, *560*, 561
— day and night, 551
— distant, 532
— monocular, 561-2
— plastic, 563
— psychology of, 569 ff.
— single and double, 564
— upside-down, 577-8
— *see also* Sight
Visual angle, 545
— cells, 421, *423*
— cortex, 421, *423*
— purple, 318
Vitamin[s], 318 ff.
— study of, 329
— A, 318-21, 553
— — deficiency, 320
— B complex, 321
— — deficiency, 321-2
— C, 322, *323*
— — deficiency, 322
— — in potato, 324
— D, 324, 477
— — excess, 327
— — in pregnancy, 325-7
— E, 327-8
— G, 328
— H, 328-9
— K, 329
— P, 329
— T, 328
Vitreous body, 537
Vocal cords, 221, *226*, 227-9
— false, 229
Voice, 230-1
— "breaking" of, 228
— varieties of, 228
Von Baer, K. E., 29
Von Bülow, H., 452
Vowels and consonants, 230-1

W

Walking, machinery of, *124*, 134-5
Wall, arterial, *159*, *163*
— of heart, 143-4
— of tooth, 97
Wall of vein, *159*
Walnut, as brain model, 414
Watch, comparison with p[...] plasm, 3-4
Water, *2*
— centre, 288-9
— hard and soft, 310-11
— in body, 169, *170*
— in food, 309, *310*
— metabolism, 287, *289*
— on the brain, 181, 419
— proportion in body, *310*
— swallowing, *252*
— vapour, in air, 211
Wax glands of ear, 513, *516*
Weight, of body, 66-7
— — regulation of, 331
— — time needed to do[...] 307, *308*
— estimating, 567
— of brain, 446-7
Whale, 446
— taste-buds of, 491-2
Wharton, jelly of, 32
Wheat-germ oil, 328
Wheat grain, *317*
Whey-protein, 258
Will and seasickness, 511
Window membranes, 524
Windpipe, 45, 211, *220*, *22*[...] 248
Wisdom teeth, 100
Woman, bodily developmen[...]
Womb, *582*, 597-8, *600-1*
— *see also* Uterus
Wood, 457
Woodall, John, 318
Wool, *351*, 353
Word-formation, 442
Word memory, 437-40
Worms, 172
Worry and digestion, 261
Wound[s], 187-9
— sepsis, 199
Wrist, 55, 79
Writing centre, 437

X

Xerophthalmia, 320

Y

Yeast, 242, 321, 338

Z

"Zenith," balloon, 205, *206*
Zinc chloride, *377*
Ziska, 462
Zola, 502

Published 1948.
Made and printed in Great Britain by Odhams (Watford) Ltd., Watford.
S.148 TQ.